WORKING PAPERS

No. 9

The use of aquatic macrophytes to assess water quality changes in some Galloway lochs; an exploratory study

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Abstract

The littoral aquatic macrophyte flora of 31 Galloway lochs was surveyed in 1983-84. Despite methodological limitations, differences between contemporary and documentary floristic data suggest oligotrophication in 8 out of 23 sites since 1904-5. The appearance of *Sphagnum spp.* in Loch Fleet, together with an apparent loss of calcicole species from other sites, may represent a floristic response to water acidification.

CONTENTS

1. INTRODUCTION

Aquatic macrophytes not only represent a significant component of the primary production within a lake system, but also provide habitats essential for invertebrate life (Kenlan et al. 1984), which in turn comprise an important food supply for predators, notably fish. Since the floristic composition of aquatic macrophytes within lakes alters in response to changing water quality (Almer et al. 1977), the effect upon the lake ecosystem can be profound. Aquatic macrophyte species' response to such change can therefore be used to infer water quality changes by comparing early documentary with contemporary floristic data (e.g. Roelofs 1983).

In conjunction with extensive diatom and water chemistry sampling of 31 Galloway lochs in 1983-84, a simple exploratory botanical survey of the littoral, higher aquatic plantlife at each site was conducted. This working paper seeks to ascertain the nutrient status of the lochs using aquatic macrophyte date by :

i) outlining the relationship between aquatic plantlife and water chemistry.

ii) presenting preliminary distributional data of aquatic macrophytes collected in 1983-84.

iii) comparing the contemporary data with those previously generated in 1904-5 (West 1910).

iv) discussing possible factors which might have affected water quality in Galloway.

2. BACKGROUND

2.1 Water quality and aquatic macrophyte distribution

The distribution of aquatic macrophytes is predominantly determined by water chemistry, particularly conductivity (Seddon 1967, 1972) and alkalinity (Spence 1967). Furthermore, the ecological tolerance of most aquatic species has been determined; some have a wide trophic tolerance, others are restricted to nutrient rich waters (Table 1). A lake consequently supports a flora which reflects *inter alia* the inherent water quality conditions; indeed, Scandinavian lakes have been traditionally classified on the basis of their plant-life (Jensén 1979). Substrate characteristics also determine the actual distribution of different aquatic species within a lake, while competition is also an important influence. For instance, ubiquitous oligo-dystrophic species are suppressed or precluded from base-rich waters by strong competition from eutrophic species (Seddon 1972).

Table 1 The trophic tolerance of aquatic macrophytes according to Seddon (1972)

Trophic status	Trophic tolerance range	Example species	Typical conductivity*
1. EUTROPHIC		*Potamogeton lucens*. *Myriophyllum spicatum*.	$>200\ \mu S\ cm^{-1}$
2. moderately EUTROPHIC		*Potamogeton crispus*.	150-200 "
3. MESO-TROPHIC		*Lemna minor*.	100-150 "
4. OLIGO-TROPHIC		*Potamogeton perfoliatus*.	50-100 "
5. DYSTROPHIC		*Isoëtes lacustris*	< 50 "

Significant changes in water quality will induce a predictable floristic response. Consequently, a chronological record of the aquatic macrophyte flora, obtained from pollen diagrams, or repeated botanical surveys of a lake over a period of decades, should indicate a history of water quality conditions. A well-documented example is the floristic response to progressive eutrophication in the Norfolk Broads since the 19th century (e.g. George 1977, Jackson 1978, Phillips *et al.* 1978, Boorman and Fuller 1981). Little effort, however, has been directed toward the floristic response in lakes subject to recent acidification, particularly in upland areas.

2.2 The context of water quality change in upland waters

The trophic status of lakes in glaciated upland areas would be expected to decline progressively after a glacial retreat, as the base-rich soils become leached, and peat bogs develop (Iversen 1954, Birks 1973). Man, however, has had a considerable modifying influence, contribution both to the acidification - oligotrophication and eutrophication of lakes (Table 2).

Table 2 Modifying influences on upland lake water quality, with special reference to Human Activity

a) OLIGOTROPHICATION (nutrient impoverishment)

1. Catchment leaching and peat-bog formation (long-term)
2. Afforestation ? (acid run-off ?)
3. Acidic precipitation
4. Peat erosion (associated with water level rise)

continued.....

Table 2 (continued)
b) EUTROPHICATION (nutrient enrichment)
1. Erosion of base-rich soil in catchment (caused by a number of factors: deforestation; pre-afforestation ploughing; heather burning ?; shoreline erosion associated with water level rise). MAINLY SHORT-TERM
2. Fertilizer input - run-off associated with agriculture OR periodic application of fertilizers to plantation forestry
3. Sewage input
4. Lime application (indirect factor) RECENT

Aquatic macrophyte evidence for longer-term oligotrophication has been inferred from pollen diagrams. From lake sites on Skye, Birks (1973), has shown that since the early post-glacial period, there has been a consistent decline and extinction of *Myriophyllum spicatum*, a base-demanding aquatic species.

Recent oligotrophication or acidification of lakes has been identified from documentary evidence generated during the last 100 years. For instance, a progressive decline in previously dominant *Lobelia - Isoëtes - Littorella* communities, and a concomitant proliferation of *Sphagnum spp.* and/or *Juncus fluitans* has been recorded in Sweden (Grähn *et al.* 1974, Grähn 1977), the Netherlands (Nilssen 1980, Roelofs 1983) and North America (Hendrey and Vertucci 1980). Both *Sphagnum* and *J. fluitans* thrive in very acidic waters (pH <4.0), often representing the only aquatic macrophytes therein (Roelofs 1983). Blanketing the substrate, it has been proposed that extensive mats of *Sphagnum* prevent nutrient exchange between sediment and water, promoting oligotrophication, and that the high cation exchange capacity of the living tissue may increase water acidity and so retard bacterial decomposition of organic detritus. A consequence is an aquatic environment of reduced potential for a diverse invertebrate fauna (Grähn *et al.* 1974; Kenlan *et al.* 1984).

A reduction in species richness, and associated floristic changes in certain Dutch ponds also suggests that oligotrophication and lake acidification are linked (van Dam and Kooyman-van-Blokland 1978).

These results were obtained by comparing floristic data in historical documents with contemporary field surveys. However, despite the availability of suitable base-line data (e.g. West 1910, Pearsall 1920, Spence 1964, Seddon 1972, Stokoe 1983), no comparable studies of recently-acidified lakes have been undertaken in the British Isles (cf. Fry and Cooke 1984).

3. THE EXPLORATORY STUDY

This exploratory study was conducted as an addendum to an intensive survey of 31 Galloway lochs involving simple bathymetry, water chemistry, surface sediment and diatom sampling (Flower and Battarbee, in preparation). As such, the sampling strategy for aquatic macrophytes was severely restricted by the lack of time and suitable equipment. Consequently, with the exception of Loch Fleet, the data cannot be confidently quantified. The main purpose in presenting the preliminary data is therefore to confirm the potential and feasibility of a more comprehensive comparative study, and stimulate interest in a field of research as yet unexplored in the British Isles.

3.1 Galloway as a suitable study site

The Galloway region of south-west Scotland represents a highly suitable site for an integrated study of aquatic macrophyte change in relation to recent acidification because :-

i) the area contains a large number of both upland and lowland lochs (n > 100) in a comparatively small area (3500 km^2)

ii) variation in solid geology, notably the presence of granite and non-granite catchments, provides areas of different potential sensitivity to acid precipitation (Figure 1).

iii) variation in catchment land-use history, notably extensive afforestation since the 1920s, provides sites subject to different run-off characteristics.

iv) there is considerable evidence of recent acidification of lochs in granite catchments, based on fossil diatom assemblages (Flower and Battarbee 1983a, Battarbee and Flower 1985).

v) there is ample documentary evidence recording the past floristic composition of many lochs. West (1910) sampled 72 Galloway lochs in 1904-5, of which nine were re-surveyed by Spence (1964) during 1958-61.

3.2 Objectives

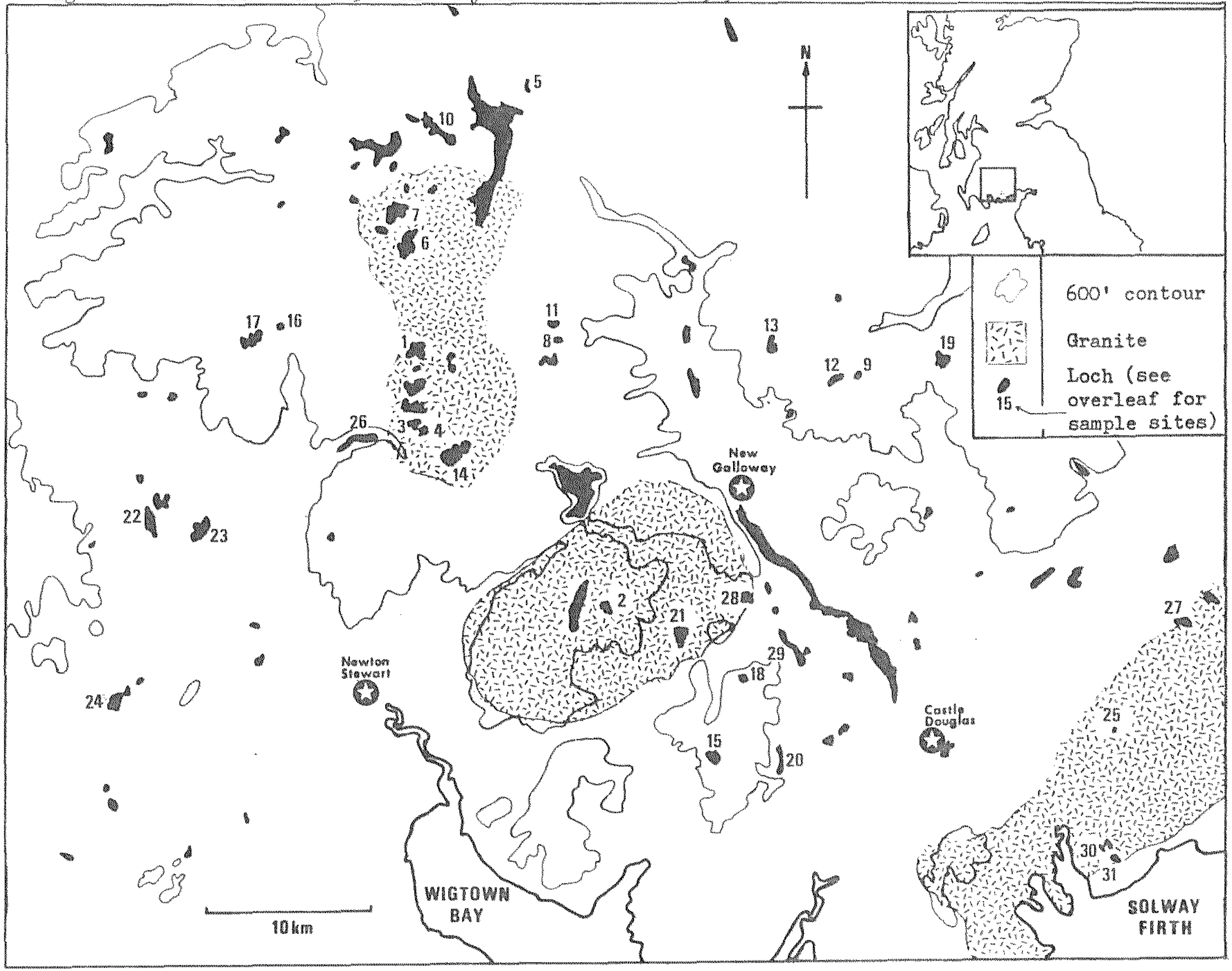
Within the considerable constraints imposed on the sampling strategy, the main objective was to list, and wherever possible determine, the distribution and abundance of aquatic macrophytes growing in the near-shore aquatic zone of 31 Galloway lochs, chosen to reflect a wide range of altitude, land-use and water quality. Secondly, to compare the contemporary flora with that documented by West 80 years beforehand, and, by assigning a trophic status to each loch (based on the aquatic macrophyte flora), produce a preliminary assessment of water quality change between 1904-5 and 1983-84.

3.3 Methods

3.3.1 West's 1904-5 Survey

In 1904-5, George West surveyed the littoral and submergent flora of 72 Galloway lochs from a boat propelled by a hired "worthy". Submergent vegetation was dredged up using a grab or rake; where a boat was unavailable (e.g. Loch Dee, L. Macaterick and L. Riecawr), West walked the shoreline examining the remains of submergent species from the strand-line. Three or four small lochs were covered thus, each day. Both cryptogams and higher phanerogams were recorded; the floristic record, however, varied considerably according to site. For instance, a single species might cover a number of adjacent lochs with similar floras (e.g. Loch Barscobe, L. Brack, L. Howie and L. Skae). On the other hand, a detailed description of species' abundance and distribution (occasionally supported by photographic evidence), is documented for individual sites such as Loch Enoch, Lochenbreck loch, Lochinvar loch, L. Skerrow, L. Stroan, L. Trool, L. Woodhall and L. White.

Figure 1   The location of 31 Galloway lochs visited in 1983-84



Key to the sampled lochs illustrated in Figure 1

West's data are therefore primarily descriptive, i.e. based on species presence/absence. However, West emphasised that the absence of a particular species from his list did not necessarily imply that it did not occur in an unsampled part of the loch. Conversely, frequent expert advice from other specialist botanists probably ensured that species identification was correct. Specimens placed in herbaria would, however, represent the most valuable record of West's 1904-5 survey.

3.3.2 The exploratory survey - littoral sampling

The contemporary survey was conducted during two periods in July 1983 and May 1984, and involved 31 sites (Figure 1). With the exception of two lochs (L. Harrow, L. Skae) boat sampling was not possible. The littoral vegetation was simply mapped from walking around the lochshore (Table 3). Water clarity was good (secchi disc depth varied between 2m and 6m), so vegetation distribution in the littoral zone could easily be determined. Abundance was assessed on a subjective scale comprising the criteria 'present' (rare), 'locally frequent', and 'abundant'.

As the key species indicating water quality change are most likely to be submergent representatives occupying an offshore habitat, the confidence with which the contemporary species lists are presented is strictly limited. Examination of strandlines, characteristic of the windward shores, yielded valuable data about the submergent flora but compatibility with West's data is still far from ideal. Indeed, time precluded detailed collection and examination of cryptogens from the shore and littoral areas.

Lochshore sampling difficulties included swarms of biting midges in late July. West encountered similar problems, having to rest up for three days in 1905 to recover from temporary blindness caused by

Table 3 The percentage of shoreline covered during the exploratory survey of littoral aquatic macrophytes of 31 Galloway lochs

Loch	National Grid Reference	Percentage shoreline surveyed		Month of survey
Arthur	NX 904688			July 1983
Clonyard	NX 857554		W	July 1983
Enoch	NX 445851		W	May 1984
Fern	NX 863624			July 1983
Fleet	NX 560698		W	July 1983
Howie	NX 697834		W	May 1984
Kirrieroch	NX 363865			July 1983
Lochenbreck	NX 643655		W	July 1983
Lochinvar	NX 548854		W	May 1984
Long Loch of Glenhead	NX 446808		W	July 1983
Maberry	NX 286750	75		May 1984
Macaterick	NX 440913		W	May 1984
Mannoch	NX 664605			May 1984
Minnoch	NX 530857		W	July 1983
Muck	NX 513007			May 1984
Ronald	NX 265644		W	May 1984
Round Loch of Glenhead	NX 450804		W	July 1983
Skae	NX 710837		W	May 1984
Skerrow	NX 606682		W	May 1984
Stroan	NX 644704		W	July 1983
Urr	NX 760845			May 1984
Whinyeon	NX 625608		W	May 1984
White	NX 864547		W	July 1983
Woodhall	NX 673675		W	July 1983
Finlas	NX 460983		W	May 1984
Harrow	NX 527867	50 - 75	W	July 1983
Riecawr	NX 434934		W	May 1984
Trool	NX 412798		W	May 1984
Dee	NX 467790		W	July 1983
Moan	NX 346858	25		July 1983
Ochiltree	NX 317745			July 1983

W = surveyed by West in 1904-5 (West 1910)

* = also surveyed in July 1984

midge and cleg bites.

3.3.3 Semi-quantitative survey of Loch Fleet

In July 1984, Loch Fleet was more comprehensively surveyed. Eleven transects, perpendicular to the shore were selected, and along each, 3 quadrats (0.0625 m^2 area) were sampled at depths of 0.0, 0.5, 1.0 and 1.5 m. Individual species abundance was assessed as percentage cover, and samples taken back to the laboratory for identification. Presence/absence data were obtained from material collected from 80 Ekman grab samples taken from a boat. The position of each sample site was determined from two, shore-based, plane-tables.(Anderson, in preparation).

3.4 Results

The basic physical and chemical parameters of the water quality in each sampled loch are presented in Table 4. Altitude ranged between 32m and 493m O.D., pH between 4.4 and 7.6, and conductivity between 29 and 116 $\mu S\ cm^{-1}$. Water chemistry within a lake can vary considerably on a diurnal and seasonal basis; consequently these data represent only a limited assessment of the aquatic environment although it must be noted that lochs with a pH less than 5.5 are well buffered by aluminium ions and exhibit little variation throughout the year (Wright and Skogheim 1983).

If each loch is assigned a trophic status, determined by the minimum nutrient tolerance limit of its aquatic macrophyte representatives, it appears that there is a correlation between nutrient level and pH of the water (Figure 2a). Furthermore, species richness appears to be significantly poorer in waters with a pH value less than 5.0 (Figure 2b).

A total of 42 higher plant species were recorded, of which 25 were typical, oligo-dystrophic representatives. Indeed, despite the

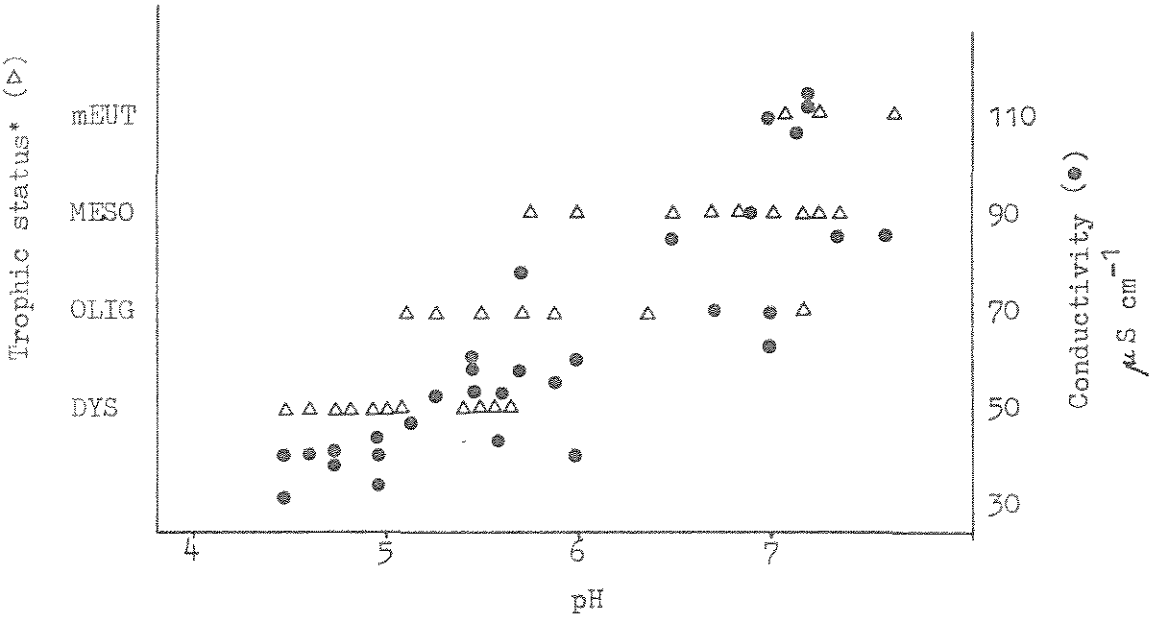
Table 4 Altitude, catchment geology, pH and conductivity of the 31 lochs sampled during the exploratory study

Loch: in ranked order of altitude	Altitude (m)	Catchment Geology	pH range	conductivity range (μS cm^{-1})
Enoch	493	G	4.5 - 4.5	29 - 51
Fleet	340	G	4.5 - 4.6	47 - 60
Long Loch of Glenhead	298	G	4.7 - 4.7	47 - 48
Round Loch of Glenhead	295	G	4.7 - 4.7	46 - 49
Muck	290	Sh	5.0 - 5.7	69 - 79
Macaterick	286	G	4.8 - 5.0	51 - 55
Riecawr	284	G	5.0 - 5.3	51 - 55
Minnoch	272	Sl	5.0 - 6.0	45 - 49
Skae	263	Sh	5.5 - 6.1	60 - 70
Finlas	254	Sh	5.5 - 5.7	57 - 68
Harrow	247	Sl	4.9 - 5.0	38 - 49
Howie	232	Sh	5.4 - 5.6	64 - 76
Lochinvar	227	Sh	6.3 - 7.1	65 - 77
Dee	225	G	4.9 - 5.9	30 - 73
Whinyeon	216	Sh	6.7 - 7.0	70 - 108
Kirrieroch	213	Sh	5.0 - 5.1	48 - 70
Moan	205	Sh	4.7 - 5.9	57 - 89
Lochenbreck	198	Sh	6.3 - 7.0	71 - 108
Urr	190	Sh	6.0 - 6.4	58 - 68
Mannoch	128	Sh	6.1 - 6.5	85 - 115
Skerrow	127	G	5.2 - 5.5	53 - 79
Maberry	118	Sh	4.8 -7.1	110 - 111
Ochiltree	104	Sh	6.0 - 6.4	68 - 110
Ronald	101	Sh	6.2 - 7.3	88 - 111
Fern	78	G	6.7 - 7.1	109 - 113
Trool	75	Sh	4.9 - 5.3	37 - 62
Arthur	73	G	6.8 - 7.6	87 - 110
Stroan	70	G	4.4 - 5.6	46 - 87
Woodhall	53	Sh	6.6 - 6.9	91 - 112
Clonyard	34	G	6.8 - 7.1	113 - 115
White	32	G	7.0 - 7.1	114 - 116

Geology: G Granite
Sh Shales / greywackes
Sl Slates

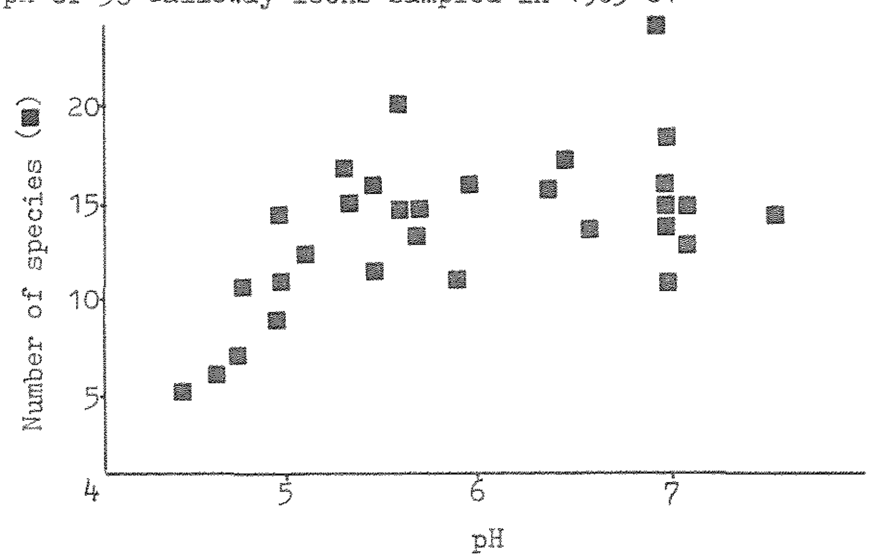
pH and conductivity sampled in July 1983, May and November 1984; date supplied by R. Flower

Figure 2a The relationship between inferred trophic status, conductivity and pH of 31 Galloway lochs surveyed in 1983-84



* deduced from macrophyte flora
mEUT; moderately eutrophic: MESO; mesotrophic: OLIG; oligotrophic: DYS; dystrophic

Figure 2b The relationship between littoral macrophyte species richness and pH of 30 Galloway lochs sampled in 1983-84



Data from Loch Minnoch excluded due to exceptional turbidity during survey variation in altitude, catchment geology and water quality, *Juncus fluitans*, *Littorella uniflora*, *Potamogeton natans*, *Carex rostrata*, *Eleocharis palustris* and *Equisetum fluviatile* occurred in more than 75% of the sites (Table 5).

In many lochs (e.g. L. Kirrieroch) the effect of wind exposure on plant distribution was clear (Appendix). Exposed eastern shorelines were predominantly rocky and devoid of higher plant cover; by contrast sheltered embayments characterised by finer sediment often supported emergent reed growth.

3.4.1 Floristic and inferred water quality changes between 1904-5 and 1983-84

Twenty-two of the 31 sites were previously visited by West in 1904-5, and the respective data are presented in Table 6. The contemporary data for L. Maberry are compared with those data collected by West from L. Dornell, a similar water-body less than 100m distant; 23 lochs therefore provide the basis for a preliminary comparative assessment. Since the respective sampling methods used in 1904-5 and 1983-84 are not satisfactorily compatible the data must be treated with caution and only tentative conclusions drawn.

(a) Comparison of emergent and floating vegetation data

One strategy is to consider only floating and emergent vegetation from both data sets: these types of vegetation are most likely to have been recorded by both observers, and changes in distribution or abundance most likely to be real. Unfortunately, emergent vegetation, with few exceptions (e.g. *Typha spp.*) has a ubiquitous tolerance range and therefore unlikely to be useful for assessing water quality change *per se*. However, floristic change produced by this strategy is summarised in Table 7.

The most consistent floristic change is represented by an increase

Table 5 The frequency distribution of littoral aquatic macrophytes recorded in 31 Galloway lochs during 1983 - 84

	SPECIES		Trophic status of loch: DYS	OLIG	MESO	mEUT	TOTAL
		n =	11	8	9	3	31
	(Fontinalis antipyretica)	(5)	4	8	6	–	18
SUBMERGENT/FLOATING SPECIES	Callitriche hamulata	(4)	–	6	5	1	12
	Callitriche stagnalis	(3)	–	–	4	1	5
	Elatine hexandra	(3)	–	–	2	–	2
	Elodea canadensis	(4)	–	–	4	1	5
	Isoëtes echinospora	(5)	3	1	1	–	5
	Isoëtes lacustris	(5)	9	7	6	–	22
	Juncus bulbosus. fluitans	(5)	10	8	6	1	25
	Lemna minor	(3)	–	–	1	–	1
	Littorella uniflora	(5)	10	8	8	3	29
	Lobelia dortmanna	(5)	10	7	6	1	24
	Myriophyllum alterniflorum	(5)	2	6	8	1	17
	Nuphar lutea	(5)	2	6	3	1	12
	Nuphar pumila	(5)	1	–	–	–	1
	Nymphaea alba	(5)	3	4	3	–	10
	Polygonum amphibium	(3)	–	–	1	–	1
	Potamogeton alpinus	(5)	–	–	2	–	2
	Potamogeton berchtoldii	(4)	–	–	1	–	1
	Potamogeton crispus	(2)	–	–	–	3	3
	Potamogeton gramineus	(3)	–	–	1	1	2
	Potamogeton natans	(5)	8	7	8	2	25
	Potamogeton perfoliatus	(4)	–	–	2	1	3
	Potamogeton polygonifolius	(5)	1	–	–	–	1
	Potamogeton praelongus	(3)	–	–	2	–	2
	Ranunculus peltatus	(4)	–	–	1	1	2
	Sparganium angustifolium	(5)	4	4	3	1	12
	Subularia aquatica	(5)	3	2	1	–	6
	Utricularia minor	(5)	1	–	–	–	1
	Utricularia vulgaris agg.	(5)	1	–	–	–	1
EMERGENT SPECIES	Alisma plantago-aquatica	(4)	–	–	4	2	6
	Carex lasiocarpa	(5)	4	3	3	–	10
	Carex rostrata	(5)	10	8	9	3	30
	Cladium mariscus	(3)	–	–	1	–	1
	Eleocharis palustris	(5)	8	8	9	2	27
	Equisetum fluviatile	(5)	8	7	9	3	27
	Glyceria fluitans	(5)	6	4	5	2	17
	Iris pseudacorus	(5)	1	–	4	2	7
	Lythrum portula	(3)	–	–	2	–	2
	Phragmites australis	(5)	6	5	4	2	17
	Schoenoplectus lacustris	(5)	3	–	6	1	10
	Sparganium erectum	(5)	–	–	3	1	4
	Typha angustifolia	(2)	–	–	–	1	1
	Typha latifolia	(3)	–	–	2	–	2
	TOTAL SPECIES RECORDED		23	18	36	24	42

Trophic tolerance of individual species shown in parenthesis (see Table 1)

Trophic status of loch determined by aquatic flora: DYS; dystrophic; OLIG oligotrophic; MESO mesotrophic; mEUT moderately eutrophic

Table 6 Littoral aquatic macrophyte species recorded from 31 Galloway lochs in 1983-84 compared with documentary data generated in 1904-5

SPECIES	LOCH / Altitude (m) / Minimum pH	Enoch	Fleet	Long Loch	Round Loch	Muck	M'catrick	Riecawr	Minnoch
	Altitude (m)	493	340	298	295	290	286	284	272
	Minimum pH	4.5	4.6	4.7	4.7	5.0	4.8	5.0	5.0
Filamentous algae	5[@]		[△]			△			
Fontinalis antipyretica	5		[+]			●	△	+	□
SUBMERGENT/FLOATING SPECIES									
Callitriche hamulata	4					+		+	
Callitriche stagnalis	3								
Elatine hexandra	3								
Elodea canadensis	4								
Isoetes echinospora	5		+		+				
Isoetes lacustris	5	[+]	[△]	[△]	[●]	+	[+]	[+]	□
Juncus bulbosus. fluitans	5	[△]	[△]	[△]	[△]	+	[+]	[●]	□
Lemna minor	3								
Littorella uniflora	5	[△]	[●]	[●]	[●]	●	[●]	[●]	□
Lobelia dortmanna	5	[+]	[●]	[●]	[●]	+	[●]	[+]	□
Myriophyllum alterniflorum	5					+	□	[+]	
Nuphar lutea	5							+	
Nuphar pumila	5								
Nymphaea alba	5						□		
Polygonum amphibium	3								
Potamogeton alpinus	5								
Potamogeton berchtoldii	4								
Potamogeton crispus	2								
Potamogeton gramineus	3								
Potamogeton lucens	1								
Potamogeton natans	5			+	+	+	[+]	[+]	□
Potamogeton obtusifolius	3								
Potamogeton perfoliatus	4								
Potamogeton polygonifolius	5				+		□	□	□
Potamogeton praelongus	3								
Potamogeton pusillus	1								
Potamogeton x zizii	5								
Ranunculus peltatus	4								
Ranunculus trichophyllus	1								
Sparganium angustifolium	5	□		[+]	[+]		□	[+]	
Subularia aquatica	5						[+]	[+]	□
Utricularia intermedia	5								
Utricularia minor	5			+					
Utricularia vulgaris agg.	5								
EMERGENT SPECIES									
Alisma plantago-aquatica	4								
Carex lasiocarpa	5	+					[+]	[+]	
Carex rostrata	5	[+]	[+]	[+]	[+]	+	[△]	[+]	□
Cladium mariscus	3								
Eleocharis multicaulis	5						□	□	
Eleocharis palustris	5			[+]	[+]	+	[+]	[+]	[+]
Eleogitan fluitans	5						□	□	□
Equisetum fluviatile	5			+		+	[+]	[+]	[△]
Glyceria fluitans	5	+			+	+	+	+	□
Iris pseudacorus	5						+		
Lythrum portula	3								
Phragmites australis	5						[△]	[+]	[●]
Schoenoplectus lacustris	5								[+]
Sparganium erectum	5								
Typha angustifolia	2								
Typha latifolia	3								

@ Species trophic tolerance (see Table 1); □ species recorded by West (1910)

1983-84 abundance: + present (rare); △ locally frequent; ● abundant

Table 6 (continued)

Group	SPECIES	LOCH / Altitude (m) / Minimum pH	Skae	Finlas	Harrow	Howie	Lochinv'r	Dee	Wh'nyeon	Kirrier'ch
		Altitude (m)	263	254	247	232	227	225	216	213
		Minimum pH	5.5	5.5	4.9	5.4	6.3	4.9	6.7	5.0
	Filamentous algae	5[@]								
	Fontinalis antipyretica	5	+	△	□	+	□	+	△	+
SUBMERGENT/FLOATING SPECIES	*Callitriche hamulata*	4	+	+			+	[+]	+	+
	Callitriche stagnalis	3					●			
	Elatine hexandra	3								
	Elodea canadensis	4								
	Isoetes echinospora	5								+
	Isoetes lacustris	5	[△]	[+]	[△]	[+]		[+]	+	●
	Juncus bulbosus. fluitans	5	[△]	[●]	[●]	[△]	[●]	[△]	[●]	+
	Lemna minor	3								
	Littorella uniflora	5	[+]	[●]	[+]	[△]	[△]	[△]	[●]	●
	Lobelia dortmanna	5	[●]	[+]	[●]	[△]	□	[●]	[+]	[●]
	Myriophyllum alterniflorum	5	[+]	[△]		[+]	[●]	[+]	[+]	
	Nuphar lutea	5	+							+
	Nuphar pumila	5								
	Nymphaea alba	5	[+]	□		[+]				+
	Polygonum amphibium	3								
	Potamogeton alpinus	5								
	Potamogeton berchtoldii	4								
	Potamogeton crispus	2					+			
	Potamogeton gramineus	3								
	Potamogeton lucens	1	□			□	□		□	
	Potamogeton natans	5	[+]	[+]	[+]	[+]	+	+	[+]	+
	Potamogeton obtusifolius	3								
	Potamogeton perfoliatus	4					□			
	Potamogeton polygonifolius	5	□	□	□	□		□		
	Potamogeton praelongus	3							+	
	Potamogeton pusillus	1					□			
	Potamogeton x *zizii*	5					□			
	Ranunculus peltatus	4								
	Ranunculus trichophyllus	1								
	Sparganium angustifolium	5		□	+			[+]		+
	Subularia aquatica	5		[+]	[+]			[+]		
	Utricularia intermedia	5	□			□		□		
	Utricularia minor	5								
	Utricularia vulgaris agg.	5			●		□	□		
EMERGENT SPECIES	*Alisma plantago-aquatica*	4								
	Carex lasiocarpa	5	[△]	[+]		[△]		[+]		
	Carex rostrata	5	[●]	[●]	[△]	[△]	[+]	[△]	[+]	+
	Cladium mariscus	3								
	Eleocharis multicaulis	5		□					□	
	Eleocharis palustris	5	[△]	[+]	[+]	[△]	[+]	+	[△]	+
	Eleogitan fluitans	5		□	□			□		
	Equisetum fluviatile	5	[+]	[+]	[△]	[△]	+	[+]	[+]	
	Glyceria fluitans	5	[+]	△	[+]	[+]	+		[+]	
	Iris pseudacorus	5								
	Lythrum portula	3								
	Phragmites australis	5	[●]	□	□	[△]				
	Schoenoplectus lacustris	5	□	□	□	[△]				
	Sparganium erectum	5								
	Typha angustifolia	2								
	Typha latifolia	3								

@ Species trophic tolerance (see Table 1); □ species recorded by West (1910)

1983-84 abundance: + present (rare); △ locally frequent; ● abundant

Table 6 (continued)

SPECIES	LOCH / Altitude (m) / Minimum pH	Moan	L'ch'nbr'ck	Urr	Mannoch	Skerrow	Maberry*	Ochiltree	Ronald
	Altitude (m)	205	198	190	128	127	118	104	101
	Minimum pH	4.7	6.3	6.0	6.1	5.2	4.8	6.0	6.2
Filamentous algae	5@	Δ						Δ	
Fontinalis antipyretica	5	+	+	+	+	[Δ]	●	+	[●]
SUBMERGENT/FLOATING SPECIES									
Callitriche hamulata	4	+		Δ	+		+	+	
Callitriche stagnalis	3		+		+				
Elatine hexandra	3								+
Elodea canadensis	4				+				+
Isoetes echinospora	5								
Isoetes lacustris	5		[Δ]	+			[+]	+	[+]
Juncus bulbosus. fluitans	5	+	[+]	+	+	[+]	[+]	+	[+]
Lemna minor	3								
Littorella uniflora	5	+	[●]	●	●	[Δ]	[●]	Δ	[●]
Lobelia dortmanna	5		[●]	+		[●]	[Δ]	●	[+]
Myriophyllum alterniflorum	5		+	●	Δ	[+]	Δ	Δ	[+]
Nuphar lutea	5	Δ				[Δ]	[+]	+	Δ
Nuphar pumila	5								
Nymphaea alba	5	Δ	[+]			[+]	□	+	□
Polygonum amphibium	3			+					
Potamogeton alpinus	5			+					□
Potamogeton berchtoldii	4								
Potamogeton crispus	2								
Potamogeton gramineus	3								
Potamogeton lucens	1						□		□
Potamogeton natans	5		+	+			+	+	+
Potamogeton obtusifolius	3								□
Potamogeton perfoliatus	4		+						
Potamogeton polygonifolius	5		□			□	□		□
Potamogeton praelongus	3				+		□		
Potamogeton pusillus	1								□
Potamogeton x *zizii*	5								
Ranunculus peltatus	4			+					
Ranunculus trichophyllus	1								
Sparganium angustifolium	5	+	[+]						□
Subularia aquatica	5								
Utricularia intermedia	5								
Utricularia minor	5								
Utricularia vulgaris agg.	5								
EMERGENT SPECIES									
Alisma plantago-aquatica	4				+				
Carex lasiocarpa	5					[Δ]			[+]
Carex rostrata	5	Δ	[Δ]	Δ	●	[Δ]	[+]	+	[+]
Cladium mariscus	3								
Eleocharis multicaulis	5		□						
Eleocharis palustris	5	+	[Δ]	+	Δ	[+]	+	+	[+]
Eleogitan fluitans	5								[+]
Equisetum fluviatile	5	+	+	+	+	[Δ]	[+]	+	[Δ]
Glyceria fluitans	5		+				+	+	+
Iris pseudacorus	5				+		□		
Lythrum portula	3				+				+
Phragmites australis	5	+	[Δ]	+		[+]	[+]	+	
Schoenoplectus lacustris	5			+	Δ				[Δ]
Sparganium erectum	5								
Typha angustifolia	2								
Typha latifolia	3				+				

@ Species trophic tolerance (see Table 1); □ species recorded by West (1910)

1983-84 abundance: + present (rare); Δ locally frequent; ● abundant

* West's data from nearby Loch Dornell

Table 6 (continued)

Group	SPECIES	Trophic tolerance@	Fern	Trool	Arthur	Stroan	Woodhill	Clonyard	White
	LOCH		Fern	Trool	Arthur	Stroan	Woodhill	Clonyard	White
	Altitude (m)		78	75	73	70	53	34	32
	Minimum pH		6.7	4.9	6.8	4.4	6.6	6.8	7.0
	Filamentous algae	5				□+			
	Fontinalis antipyretica	5				□△			□
Submergent/Floating species	*Callitriche hamulata*	4					+		
	Callitriche stagnalis	3	+				+		
	Elatine hexandra	3							
	Elodea canadensis	4	+		△		+		
	Isoetes echinospora	5				+	+		
	Isoetes lacustris	5		□△		□+	+		□
	Juncus bulbosus. fluitans	5		□●		□+	□		
	Lemna minor	3	+						
	Littorella uniflora	5	△	□+	△	□●	□△	+	□+
	Lobelia dortmanna	5		□△	+	□△	□+		□
	Myriophyllum alterniflorum	5	+			□+	□+		
	Nuphar lutea	5	●	+		△	□+		△
	Nuphar pumila	5				□+			
	Nymphaea alba	5	●			+	□+	□+	□
	Polygonum amphibium	3							
	Potamogeton alpinus	5					+		□
	Potamogeton berchtoldii	4					+		
	Potamogeton crispus	2			△				□+
	Potamogeton gramineus	3			+		+		
	Potamogeton lucens	1					□		□
	Potamogeton natans	5		+	△	□+	□△	□+	□
	Potamogeton obtusifolius	3		□					
	Potamogeton perfoliatus	4	+		+				□
	Potamogeton polygonifolius	5		□		□	□		
	Potamogeton praelongus	3					□		
	Potamogeton pusillus	1		□					□
	Potamogeton x zizii	5							
	Ranunculus peltatus	4			+				
	Ranunculus trichophyllus	1							□
	Sparganium angustifolium	5				□+	+	□+	+
	Subularia aquatica	5				□+			
	Utricularia intermedia	5							
	Utricularia minor	5							
	Utricularia vulgaris agg.	5		□					
Emergent species	*Alisma plantago-aquatica*	4	△		+		+	+	□+
	Carex lasiocarpa	5					□+		
	Carex rostrata	5	△	□△	△	□△	□△	□△	□△
	Cladium mariscus	3						△	
	Eleocharis multicaulis	5							□
	Eleocharis palustris	5	△		+	□+	□△	△	
	Eleogitan fluitans	5				□			
	Equisetum fluviatile	5	●	□+	△	□+	□△	□△	□+
	Glyceria fluitans	5	+			□+			+
	Iris pseudacorus	5			+		□+	□△	△
	Lythrum portula	3							
	Phragmites australis	5		□+	●	□△	□△	□△	□●
	Schoenoplectus lacustris	5				□●	□●	□●	□●
	Sparganium erectum	5	+				+	□+	+
	Typha angustifolia	2							□●
	Typha latifolia	3						□△	

@ Species trophic tolerance (see Table 1); □ species recorded by West (1910)

1983-84 abundance: + present (rare); △ locally frequent; ● abundant

Table 7 Floristic changes in 22 resurveyed Galloway lochs between 1904-5 and 1983-4, which can be confidently presented

Loch	Floristic change between 1904-5 and 1983-84			
	Species lost	Species gained	Species declining	Species increasing
Enoch	*Sparganium angustifolium*	-	-	-
Fleet	-	*Sphagnum* spp.	-	-
Harrow	*Phragmites australis* *Schoenoplectus lacustris*	*Utricularia minor*	-	-
Howie	-	-	-	*Schoenoplectus lacustris*
Lochinvar	-	*Callitriche* spp.	-	*Juncus bulbosus. fluitans*
Lochenbreck	-	-	-	*Equisetum fluviatile*
Ronald	-	-	-	*Equisetum fluviatile*
Trool	-	-	*Equisetum fluviatile*	-
Stroan	*Eleogitan fluitans*	-	-	*Phragmites australis* *Schoenoplectus lacustris*
Woodhall	-	-	*Equisetum fluviatile*	*Phragmites australis* *Schoenoplectus lacustris*
Clonyard	-	*Cladium mariscus*	*Nymphaea alba*	*Typha latifolia*
White	-	*Nuphar lutea*	-	*Typha angustifolia*

Floristic composition of emergent vegetation in Long and Round Lochs of Glenhead, L. Macaterick, L. Riecawr, L. Minnoch, L. Skae, L. Dee, L. Whinyeon, and L. Skerrow similar in 1904-5 and 1983-84 in reedbeds (notably Equisetum fluviatile, Phragmites australis and Schoenoplectus lacustris) particularly in the lowland lochs. Even so, considerable variation between sites is evident. Phragmites and Schoenoplectus have apparently disappeared from L. Harrow (replaced by Carex rostrata ?) but increased significantly in L. Stroan (see Figure 6). In Loch Woodhall, both species have apparently displaced the previously abundant Equisetum fluviatile at the northern end (Appendix); [West (1910) noted that Equisetum at the north end of the loch was particularly large in stature "rising 3 or 4 feet out of water 6 feet deep"]. Equisetum has also evidently declined at the eastern end of Loch Trool since 1905: described by West (1910) as "abundant" in the vicinity of the delta, it is now little more than sporadic (Appendix). Conversely, Equisetum has increased in abundance along the south-west shore of Lochenbreck loch (Appendix). In Loch Clonyard, the sedge/reed margin described by West (1910) has changed little, save the appearance of Cladium mariscus on the north-east shore, and an apparent increase of Typha latifolia. The "broad belt" of Nymphaea alba present in 1905 has evidently diminished significantly (Appendix). Other than these changes, the distribution of emergent vegetation has remained broadly similar since 1904-5.

An increase in reedbeds, particularly in the lower altitude sites (e.g. L. Stroan, L. Woodhall, L. Clonyard and L. White) is probably in response to a change in littoral sediment characteristics, namely an increase in fine particulate accumulation. Spence (1967) indicated that such a change was likely to be very slow in upland lochs with glacially-scoured catchments but relatively quick in lowland, depositional "kettle-hole" lochs, a pattern confirmed by the comparative data. Dam construction and pre-afforestation ploughing are likely to accelerate sediment input in upland lochs, at least in the short-term; it is likely, therefore, that the Phragmites - Schoenoplectus reedbed situated near the influent watercourse in Loch Minnoch, and unchanged in distribution since 1904-5, is likely to increase as a result of substantial sediment input in 1983. This was caused by construction of a small hydro-electric scheme involving dam construction and modification to Loch Dungeon upstream.

(b) Comparison of the entire 1904-5 and 1983-84 data

A second, less satisfactory strategy is direct comparison between the entire data sets generated in 1904-5 and 1983-84. This assumes that the submergent vegetation debris recorded along the strandline in 1983-84 was representative of the entire loch, a highly dubious presumption. Moreover, minor changes in floristic composition derived from this comparison could be the result of natural fluctuations - small populations may decline, die out or establish within a loch at any time. However, apparent floristic changes identified by this strategy might be useful in identifying sites which warrant further intensive investigation.

The apparent loss of many broad-leaved, submergent Potamogeton species represents the most notable feature (Table 6), although lack of suitable sampling might account for this difference. If confirmed, the most significant change would be the loss of Potamogeton lucens from seven sites and P. pusillus from four sites; both species are known calcicoles (Spence 1967) and eutrophic species (Seddon 1972). Their loss would suggest a response to acidification - oligotrophication since 1904-5.

Applying the minimum trophic tolerance of species recorded at each site, individual lochs can be assigned a nutrient status in 1904-5 and 1983-84. It is evident that 10 out of the 23 lochs common to both surveys have suffered apparent nutrient impoverishment since 1904-5, while three lochs have been nutrient-enriched (Table 8). Most dramatic has been the inferred oligotrophication of Lochs Howie, Skae and Trool.

3.4.2 Aquatic macrophyte flora of Loch Fleet

It is impossible to assess possible water quality deterioration of initially oligo-dystrophic lochs using the previous presence/absence strategy. Only replicated quantitative cover abundance/biomass surveys of submergent vegetation will indicate consistent changes in floristic composition over a number of years. This strategy has revealed the decline of Lobelia-Isoëtes-Littorella communities and a concomitant proliferation of Sphagnum spp. in Sweden (Grähn et al. 1974). The 1984 Loch Fleet survey has at least provided a basis upon which future changes can be assessed.

Frequency data obtained from the littoral transects and Ekman grab samples indicate a Littorella → Lobelia → Isoëtes zonation with increasing water depth, a pattern typical of most upland soft-water lochs (Figure 3). However, sampling also revealed the widespread distribution of Sphagnum spp. (mainly S. subsecundum, but also S. compactum, S. papillosum and S. cuspidatum; P. Moore pers. comm.) between 2m and 10m depth (Figures 3 and 4). The presence of Sphagnum is important because (i) it was not revealed by the 1983 littoral survey (Appendix), (ii) it was not recorded from Fleet in 1905 (West 1910), and (iii) comprehensive surveys of other lochs may reveal its true extent in Galloway, particularly as its association with acidified waters has been highlighted (cf. Fry and Cooke 1984). The

Table 8. Water quality changes in 23 Galloway lochs 1904-5 to 1983-84 deduced from changes in their aquatic macrophyte flora

1904-5 trophic status*	1983-84 inferred trophic status*: Eutrophic	moderately Eutrophic	Mesotrophic	Oligotrophic	Dystrophic	n
Eutrophic	-	LOCHINVAR WHITE	RONALD WHINYEON WOODHALL	MAEBERRY	HOWIE TROOL SKAE	9
moderately Eutrophic	-	-	-	-	-	-
Mesotrophic	-	-	CLONYARD	-	-	1
Oligotrophic	-	-	-	DEE	STROAN	2
Dystrophic	-	-	FINLAS LOCHENBRECK	RIECAWR	ENOCH FLEET LLG RLG MACATERICK MINNOCH HARROW SKERROW	11
n	-	2	6	3	12	23

* see Table 1

LLG Long loch of Glenhead

RLG Round loch of Glenhead

Figure 3 The depth distribution of four principal aquatic macrophyte species in Loch Fleet, July 1984

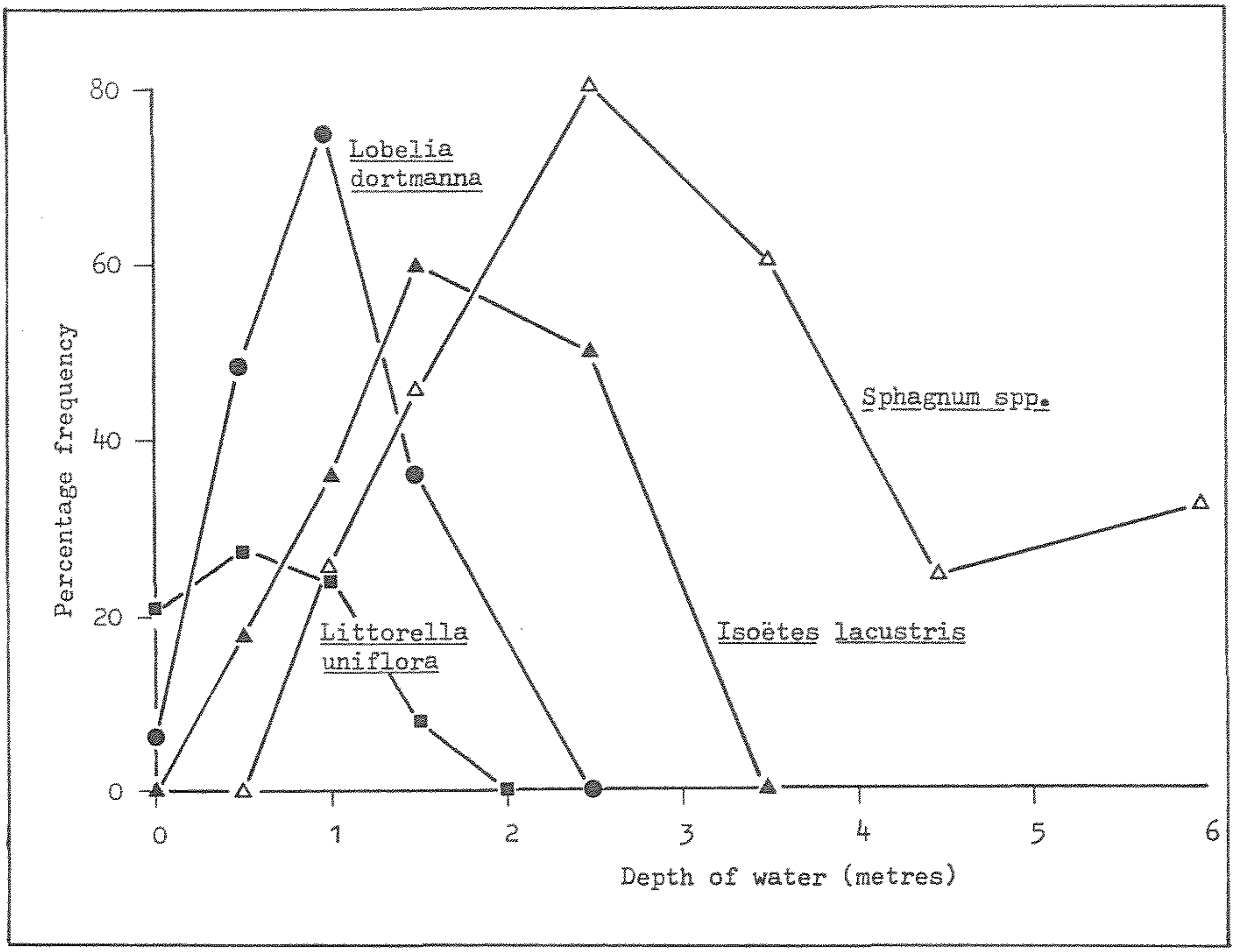
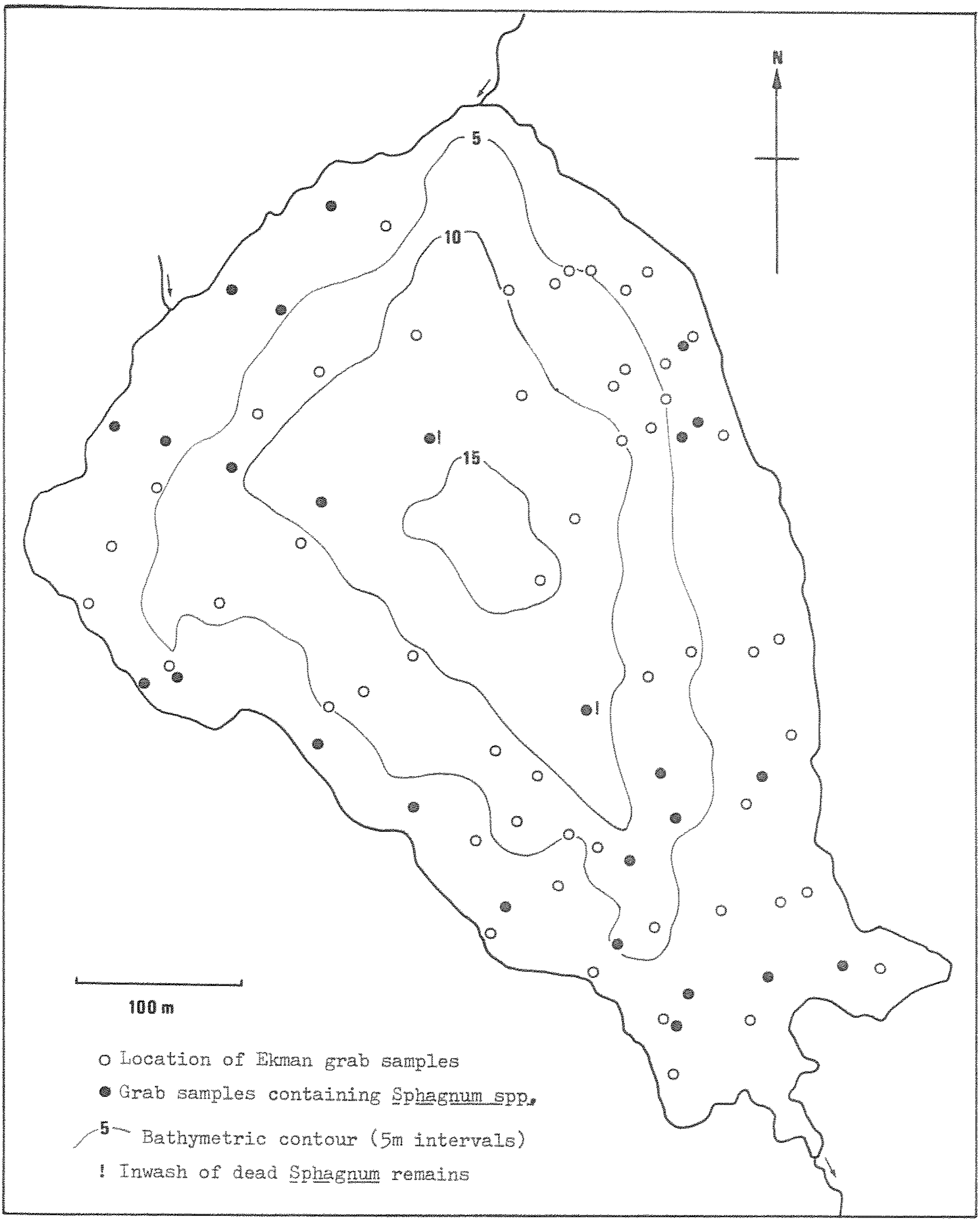


Figure 4 The distribution of Sphagnum spp. in Loch Fleet determined from 80 grab samples taken in July 1984



most likely sites to sample would be those indicating an apparent loss of *Potamogeton lucens* or *P. pusillus*.

4. DISCUSSION

The results indicate, albeit tentatively, that water quality has changed in a number of Galloway lochs since 1904-5. It is pertinent to discuss some possible factors which might affect water quality in the area.

4.1 Acid precipitation

It has been shown that, with reference to fossil diatom assemblages, five out of six selected Galloway lochs situated in granite catchments have become significantly more acid, by between 0.5 and 1.2 pH units, a process commencing between 1850 and 1925 according to site (Flower and Battarbee 1983b, Battarbee and Flower 1985). Moreover, by way of site selection, neither afforestation nor other land-use changes within the catchments were evidently responsible for the acidification. The conclusion is that increased acid precipitation since the Industrial Revolution has been the main cause of acidification.

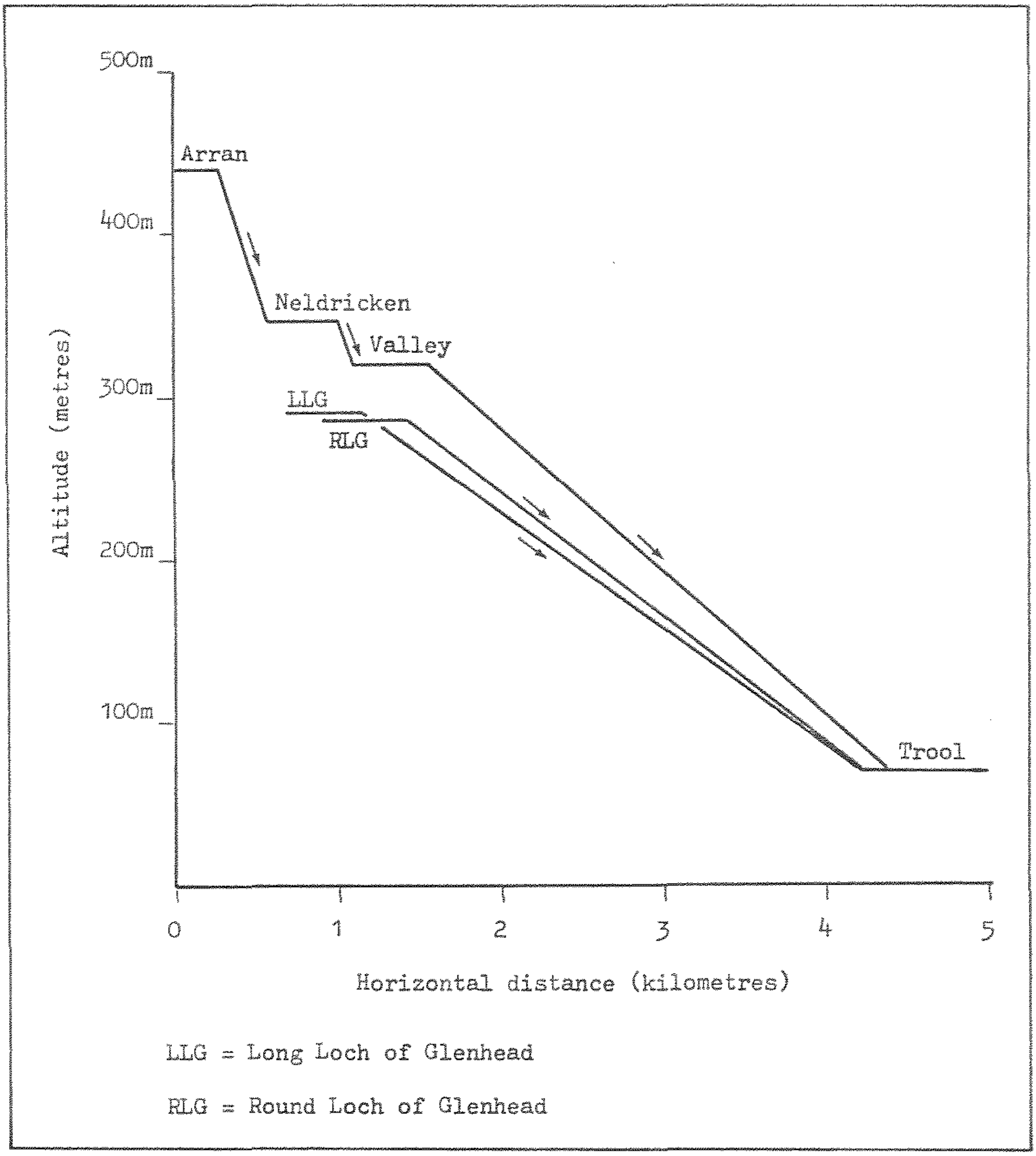
Unfortunately, each of the six sites selected for diatom analysis was historically acidic (pH < 6.0) and presumably supported an oligo-dystrophic macrophyte flora. A simple comparison of species lists produced in 1904-5 and 1983-84 cannot therefore indicate the extent of floristic response in response to acidification of these sites. Nevertheless, the apparent colonisation by *Sphagnum spp.* in Loch Fleet since 1904-5 may provide such evidence. It should be noted, however, that despite the apparent increase of *Sphagnum* in certain European and North American sites, its sub-aquatic habitat is not a recent phenomenon. *Sphagnum spp.* was recorded along the shores of at least 10 Galloway lochs in 1904-5 (West 1910); indeed West noted its unusual proliferation to a depth of 3 m at the southern end of Loch Grannoch, a site where diatom data indicate a pH of ca. 5.6 at that time, prior to acidification in the 1920s (Flower and Battarbee 1983b). Bog moss has also been recorded growing at depth in Lake Avalanche (USA) during 1880 (Hendry and Vertucci 1980), and recorded from 52% of Danish lakes with a pH less than 7.0, sampled in the 1920s (Iversen 1929).

Quantitative sampling of aquatic macrophytes in "lowland" lochs, which receive primary water direct from upland waters known to have been acidified should yield potentially-useful data, particularly if pollen diagrams and macrofossil analysis from sediment cores were obtained. This would indicate whether eutrophic/mesotrophic species (which would normally be expected to dominate the lowland-type macrophyte flora) had been replaced by oligo-dystrophic species in response to changes in water quality input from the upland sites. Loch Trool, with an input from acidified lochs (e.g. L. Valley, Round loch of Glenhead) would provide an ideal site for intensive sampling (Figure 5). The problem of lag-time between water quality change and aquatic macrophyte change could be partially alleviated by comparing variations in diatom assemblages and macrofossil/pollen remains in a dated sediment core.

4.2 Land-use change

Since the early post-glacial, many catchments have undergone considerable vegetation change. Tree stumps underlying peat, or occurring in the sub-littoral zone of some lochs (e.g. L. Skae, L. Skerrow, L. Urr) provide evidence for ancient forest. Pollen analysis (Stevenson pers. comm.) shows that blanket peat replaced the post-glacial forest in the vicinity of the Round loch of Glenhead between 3 and 5,000 years B.P. Today, the only "natural" tree and shrub vegetation (mainly Betula spp., Sorbus aucuparia, Calluna vulgaris and Vaccinium myrtillus) is confined to islands within some lochs, (e.g. L. Maberry, L. Ochiltree, Round loch of Glenhead), inaccessible to

Figure 5 The route of "primary" water from five upland lochs into Loch Trool



grazing livestock and unaffected by moorland burning and afforestation.

By the early 19th century, upland Galloway was dominated by sheep-grazing, and the landscape was dominated by wild, rocky moorland (West 1910). The dominance of Molinia within catchments was considered by West to be an important influence on loch vegetation. He suggested that the extensive mats of wind-blown, decay-resistant grass blades which accumulated on many loch floors (e.g. L. Enoch), restricted aquatic plant-growth within the photic zone.

With very few exceptions, most catchments in Galloway have been partially or extensively afforested since the 1920s (Table 9). The previous abundant supply of Molinia has therefore been reduced or curtailed. Loch Enoch, however, continues to be characterised by inblown moor-grass.

Afforestation is accompanied by (i) short-term sediment input as a result of ploughing (Battarbee et al. 1985), and (ii) possible enhanced collection of, and increased run-off by, acid substrates (Harriman and Morrison 1982). The latter effect is particularly important if coniferous trees are planted close to the lochshore. However, there is circumstantial evidence, based on the present study, that water quality change (derived from comparative aquatic macrophyte data), has taken place in non-afforested and afforested catchments alike, a pattern also indicated by diatom-based studies (Flower and Battarbee 1983b, Battarbee and Flower 1985). Moreover, water quality change (i.e. acidification-oligotrophication) has apparently occurred in granite and non-granite catchments.

Table 9 Percentage of lochshore surrounded by forest in 1930 and 1983-84

Loch (in ranked order of altitude)	Percentage of loch surrounded by forest	
	1930[a]	1983-84[b]
Enoch	-	-
Fleet	-	40.0
Long Loch of Glenhead	-	-
Round Loch of Glenhead	-	-
Muck	-	10.0
Macaterick	-	50.0
Riecawr	-	100.0
Minnoch	-	100.0
Skae	-	100.0
Finlas	-	20.0
Harrow	-	60.0
Howie	-	100.0
Lochinvar	1.0	5.0
Dee	-	40.0
Whinyeon	-	30.0
Kirrieroch	-	75.0
Moan	-	100.0
Lochenbreck	30.0	70.0
Urr	-	5.0
Mannoch	5.0	5.0
Skerrow	-	60.0
Maberry	-	40.0
Ochiltree	-	10.0
Ronald	30.0*	40.0*
Fern	20.0*	20.0*
Trool	30.0*	60.0*
Arthur	30.0*	50.0*
Stroan	-	70.0
Woodhall	30.0*	50.0*
Clonyard	-	10.0
White	40.0*	60.0*

[a] determined from Ordnance Survey maps

[b] estimated during field survey

* includes broad-leaved deciduous woodland

4.3 Dam construction

A number of the sampled lochs have been sluiced or dammed, to improve fisheries potential, or provide a supply of water for nearby settlement (Table 10). A rise in water-level causes bank

Table 10 Sampled lochs with raised water level caused by sluice or dam construction

Loch (in ranked order of altitude)	Sluice (<1.0m high)	Dam
Riecawr		+ (water supply)
Minnoch		+ (hydroelectric power)
Skae	+ (fishing ?)	
Finlas		+ (water supply)*
Lochinvar		+ (water supply)*
Whinyeon		+ (water supply)
Lochenbreck	+ (fishing)	
Urr	+ (sailing)	
Mannoch		+ (fishing - entirely man-made loch)
Ronald	+ (sailing)	
Fern		+ (fishing)
Trool	+ (fishing ?)*	
Clonyard	+ (fishing ?)	

* water level raised on more than one occasion

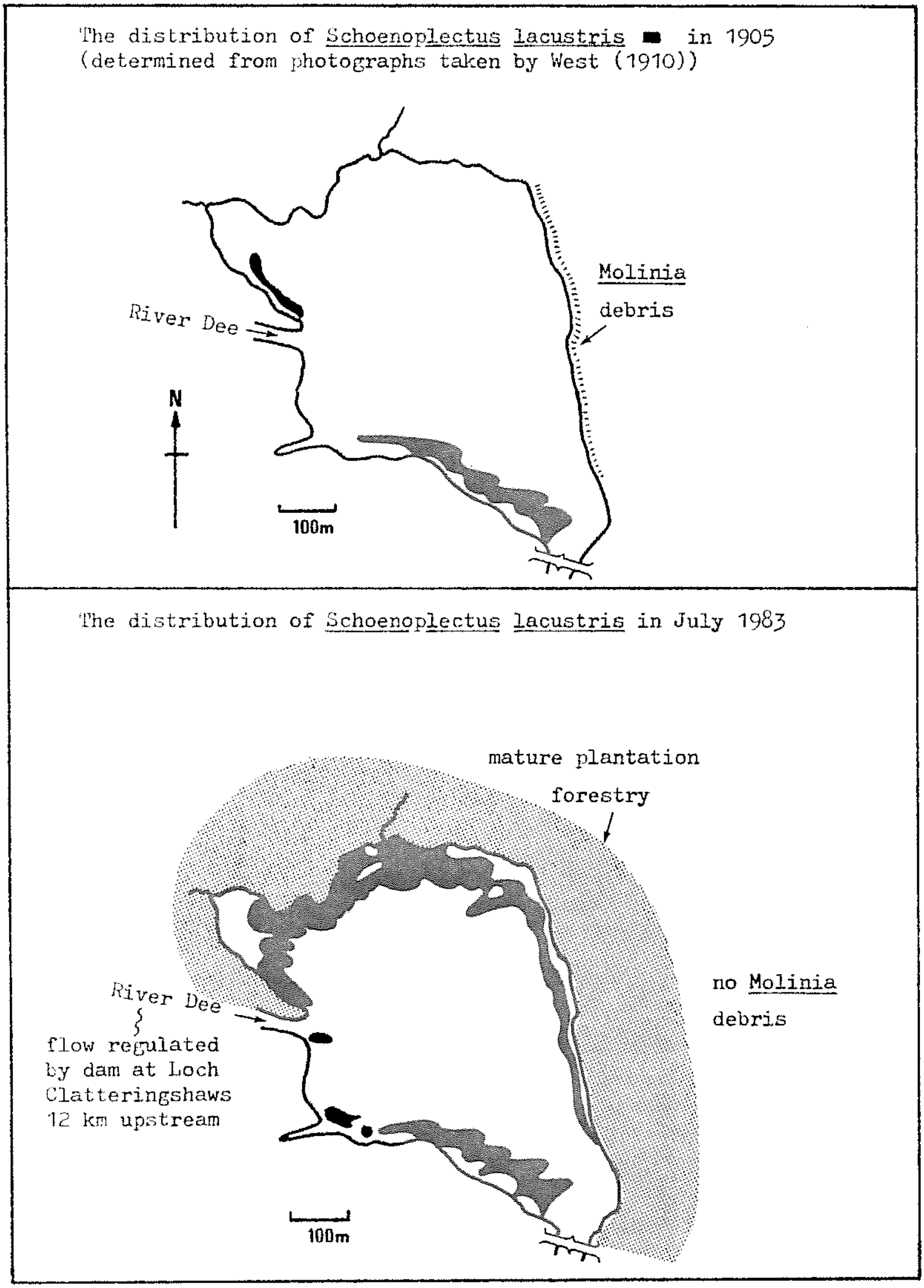
cf p.37.

erosion along the new shore-line and may change the predominant littoral substrate. For instance, due to dam construction, the sandy bays described by West (1910) along the eastern shores of Loch Riecawr, are no longer in existence; most of the shoreline and sub-littoral zone is now peaty. This substrate favours the growth of *Juncus fluitans* at the expense of *Lobelia* - *Littorella* - *Isoëtes* communities which prefer sandy areas. West (1910) also noted that after dam construction, the new peaty littoral zone had affected the relative abundance of species within the loch. Indeed, Nuphar lutea and Nymphaea alba both disappeared from L. Finlas soon after dam construction (West 1910); moreover, both are still absent today, although the reason for their disappearance and continued absence remains unclear.

Renewed shore-line erosion will effectively increase the input of sediment in the short-term. The effect upon water quality, and hence floristic composition, within a loch is unclear, but would depend on the size of the waterbody, rate of sediment input, and whether the material was base-rich (e.g. derived from glacial tills) or acidic (e.g. blanket peat). Increased accumulation of fine material might encourage reedbed growth.

Regulation of flow might also influence aquatic macrophyte distribution downstream from dams. The significant increase of Schoenoplectus lacustris reedbeds in Loch Stroan since 1904-5 may be in response to regulated inflow of the River Dee since dam construction created Loch Clatteringshaws in the mid-1920s (Figure 6). Previously, the tremendous force with which the unregulated River Dee entered Loch Stroan produced extensive scouring of the loch-bed and swept voluminous amounts of Molinia debris onto the eastern shore, forming a prominent strandline 2-3 m above dry-weather water level (see photograph in West, 1910). Today, this strandline is no longer evident, as much of the catchment around L. Stroan and the River Dee upstream, has been afforested. Indeed, the mature plantation along the northern and eastern shore-lines may provide extra shelter, and, together with a lower water level produced by the regulated flow, enable finer sediments to settle and thereby increase the potential for reedbed growth.

Figure 6 The change in distribution of Schoenoplectus lacustris in Loch Stroan between 1905 and 1983



4.4 Eutrophication and liming

An increase in nutrient supply may be the result of fertilizer application, either to improve pasture or aid forestry growth. With the exception of Lochs Stroan and Trool, which both receive primary water from upland lochs (cf. Figure 5), the lower altitude lochs, particularly those with an agricultural component of catchment land-use, as expected supported an aquatic macrophyte flora which indicated they were relatively nutrient-rich (e.g. L. Arthur, L. Fern, L. Clonyard, L. White, L. Woodhall). However, the three sites which, on macrophyte evidence, had become nutrient-enriched since 1904-5 (namely Loch Finlas, Lochenbreck loch and L. Riecawr) are located at altitudes between 198 m and 284 m. Furthermore, two naturally nutrient-rich lowland sites (e.g. L. White and L. Woodhall) had apparently been subject to nutrient impoverishment during the same period.

Nutrient-enrichment in Loch Finlas and L. Riecawr is difficult to explain because in both instances, a rise in water level caused by dam construction has exposed a predominantly peaty shoreline. Lochenbreck has an extensive hay meadow along its northern shore; fertilizer application is therefore most likely. All three lochs are well-stocked with trout and regularly fished; nutrient enrichment might therefore be associated with fisheries management.

West (1910) considered birds to be an important influence on upland loch floras, and noted that the absence of waterbirds might reduce the possibility of certain plant species colonising isolated sites. A number of gull colonies and roosts were evident in 1983-84 (Table 11), the most significant being that of ca. 500 pairs of

↓ pH → ↓ fish → ↓ birds → ↓ guano.

Black-headed gulls, *Larus ridibundus*, on the main island in Loch Enoch. Neither McBain (1929) nor West (1910) mentioned this substantial colony; indeed, McBain emphasised the lack of bird-life at L. Enoch, a site which he frequently visited. The gulls at Loch Enoch evidently do not feed there, but forage in lowland areas to the south-west, a fact gleaned from the steady traffic of birds travelling to and fro via Lochs Neldricken and Trool.

Table 11 Sampled lochs with Gull colonies or roosts in 1983-84

	Estimated size of Gull colony (pairs)	
Loch (in ranked order of altitude)	Black-headed Gull (*Larus ridibundus*)	Common Gull (*Larus canus*)
Enoch	500	-
Skae	-	10
Finlas	-	20
Lochinvar	-	10
Whinyeon	50	-
Moan	large roost (July)	-
Urr	300	-
Maberry	50	-
Ochiltree	large roost (July)	-
Ronald	100	

Substantial amounts of guano may be produced by gull colonies and roosts but its influence on the nutrient content of oligo-dystrophic waters (where most colonies were found) is unclear. However, diatoms collected from the pool on Loch Enoch island did not indicate nutrient-enrichment despite abundant guano on the submerged stones (R. Flower, pers. comm.).

Liming has recently occurred in Lochs Dee, Finlas and Muck, to protect water quality for stocked Brown Trout. The application of limestone and shells to inflow streams probably affects the aquatic macrophyte flora within the watercourses and loch itself. Indeed the apparent nutrient-enrichment of Loch Finlas may be associated with this type of management.

5. CONCLUSIONS

Despite methodological and data limitations imposed by the exploratory nature of the study, circumstantial evidence suggests :

(a) A relationship between water pH and trophic status.

(b) An impoverishment of the aquatic macrophyte flora in waters with pH values less than 5.0.

(c) Localised changes in the distribution of oligo-dystrophic species since 1904-5. An increase in fine sediment accumulation, a change in littoral substrate following a rise in water level, and inflow regulation downstream from dams are identified as possible factors producing these changes.

(d) An apparent loss of calcicole species, notably Potamogeton lucens and P. pusillus from 8 lochs. If confirmed, this would indicate floristic change in response to acidification-oligotrophication, a process which has been identified by changes in the diatom flora within Galloway. The widespread distribution of previously unrecorded Sphagnum spp. in Loch Fleet provides further evidence for this process.

(e) Nutrient-enrichment is inferred in 3 lochs since 1904-5, possibly associated with fisheries management.

Although all these conclusions are necessarily tentative, they do confirm the feasibility of assessing water quality change using aquatic macrophyte data. An integrated study of selected sites involving contemporary aquatic macrophyte surveys, together with diatom, pollen and macrofossil analysis of dated sediment cores could enable the chronology of change to be evaluated. Furthermore, the cause of any change could be indirectly tested by selecting sites with differing catchment geology and land-use histories.

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APPENDIX

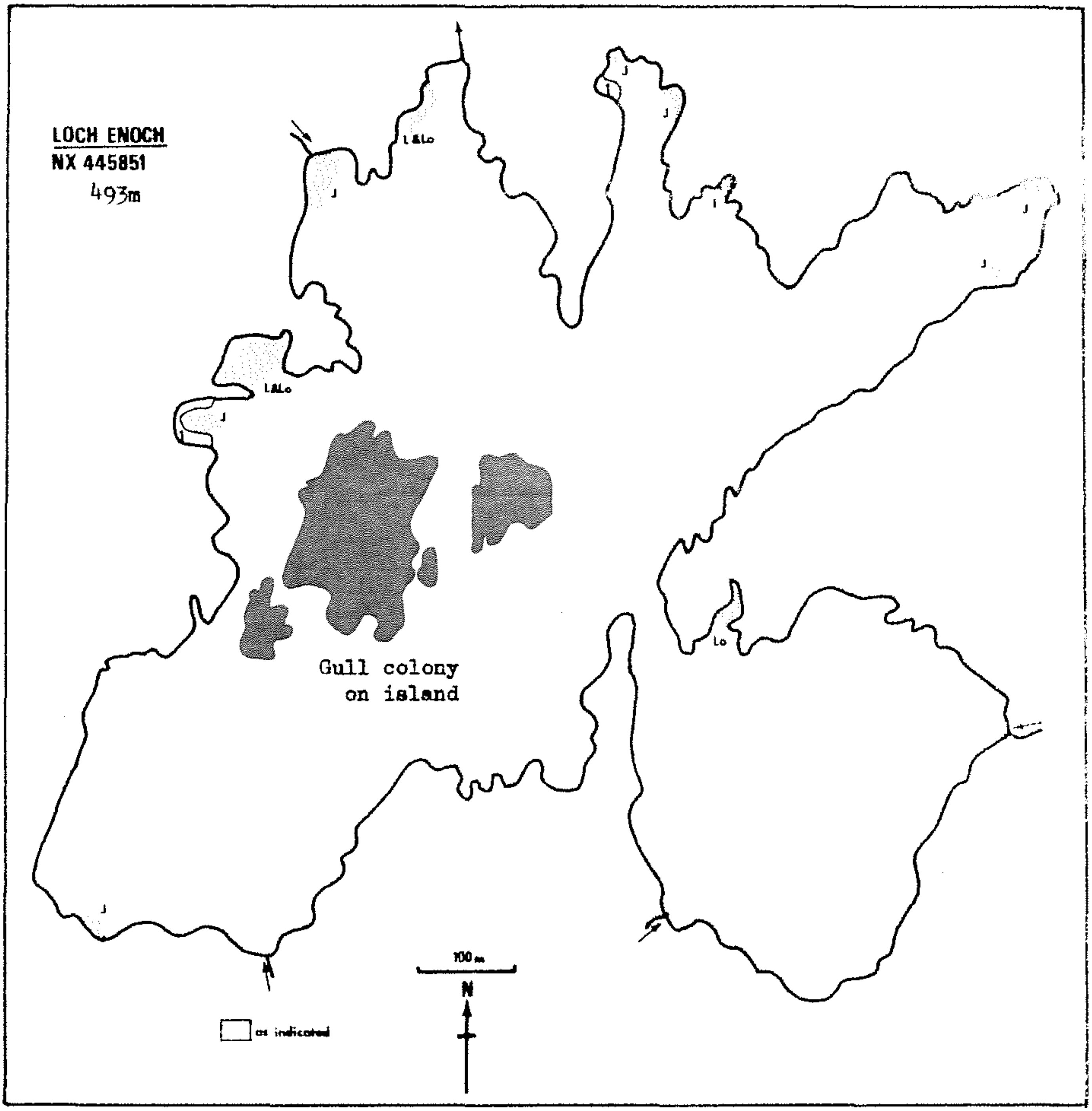
The distribution of littoral aquatic macrophyte vegetation in 30 Galloway lochs during July 1983 and May 1984.

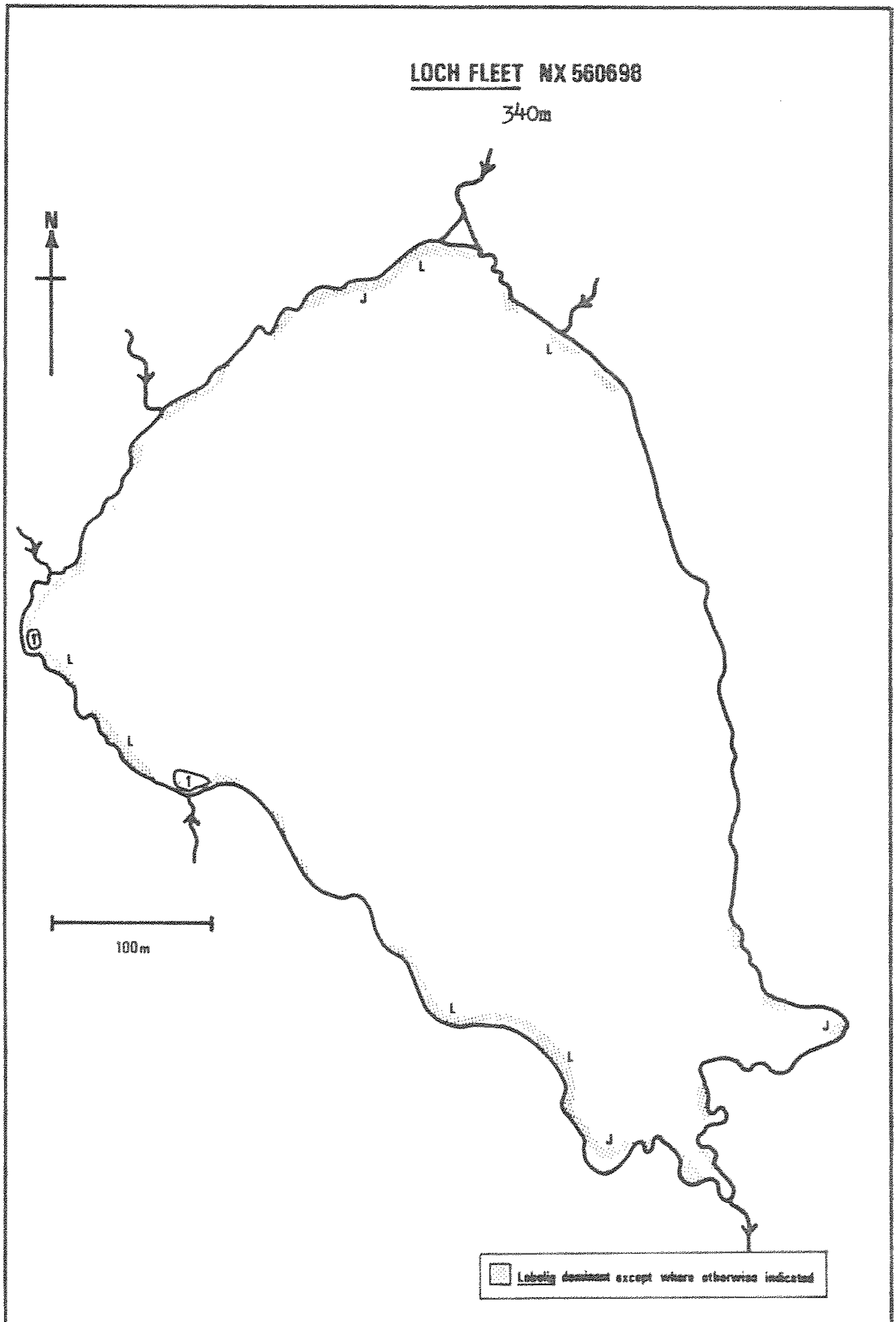
Notes.

Lochs are presented in descending order of altitude (see legend with Figure 1).
A vegetation map of Loch Dee is unavailable.
Loch islands are shaded black

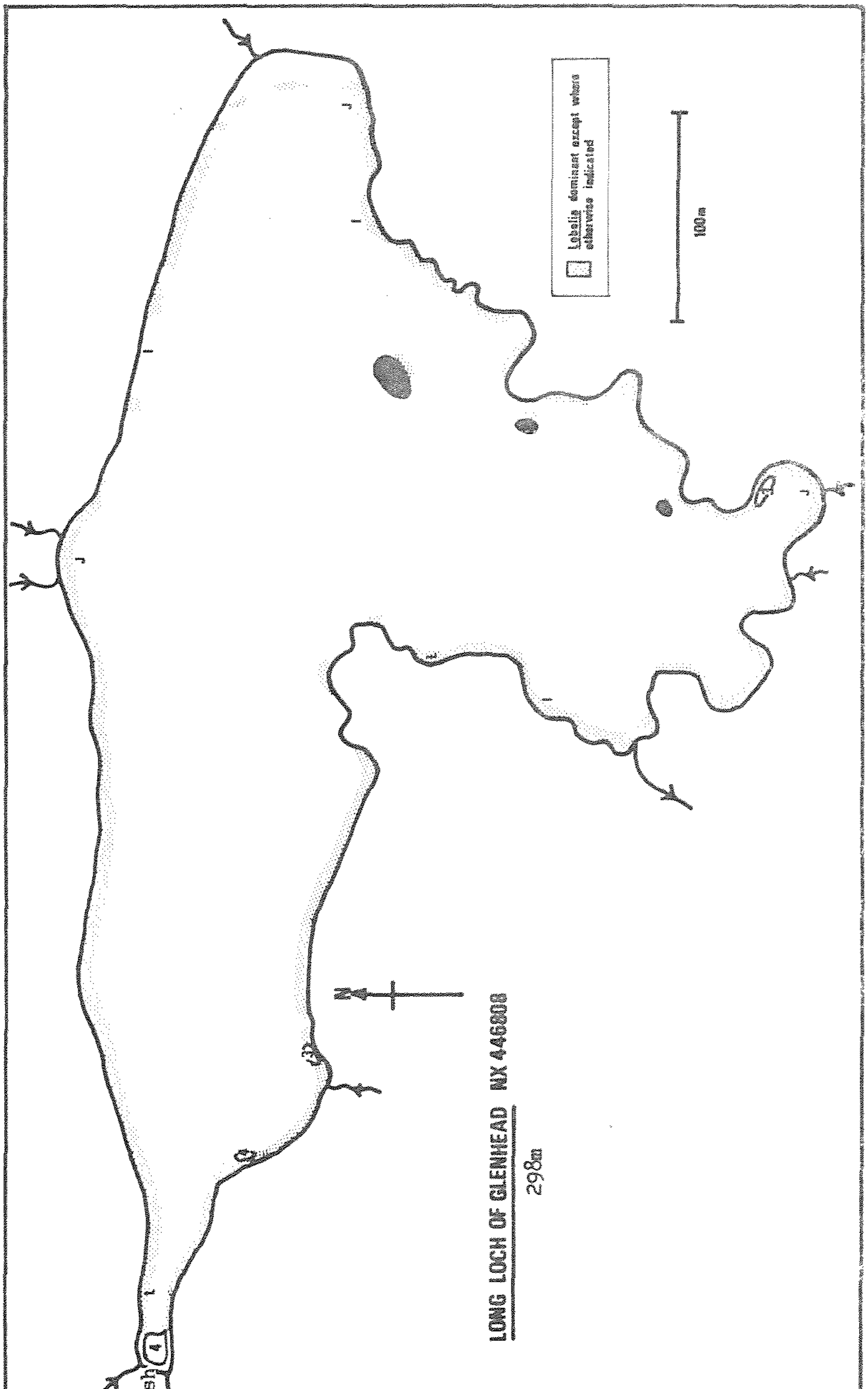
Key to vegetation included on distribution maps

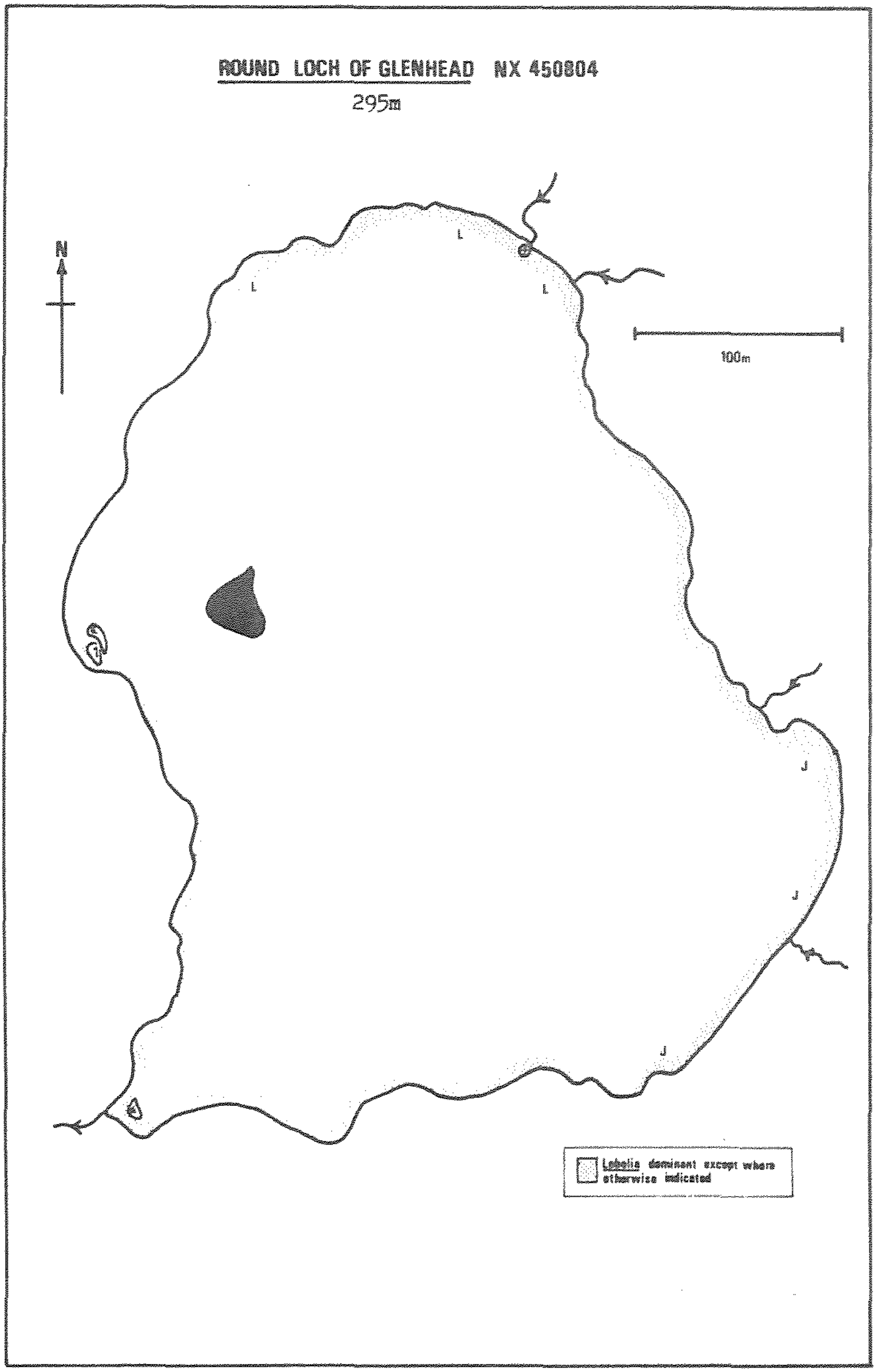
a) SUBMERGENT SPECIES (stippled shading)	
Callitriche spp.	C
Fontinalis spp.	F
Isoëtes lacustris	I
Juncus bulbosus. fluitans	J
Littorella uniflora	L
Lobelia dortmanna	Lo
Myriophyllum alterniflorum	M
Potamogeton crispus	Pc
b) FLOATING SPECIES (symbols)	
Nuphar lutea	♤
Nuphar pumila	♠
Nymphaea alba	★
Potamogeton natans	+
Sparganium angustifolium	ℓ
c) EMERGENT SPECIES (numbers)	
Carex spp.	1
Cladium mariscus	2
Eleocharis lacustris	3
Equisetum fluviatile	4
Iris pseudacorus	5
Phragmites australis	6
Schoenoplectus lacustris	7
Sparganium erectum	8
Typha angustifolia	9
Typha latifolia	10

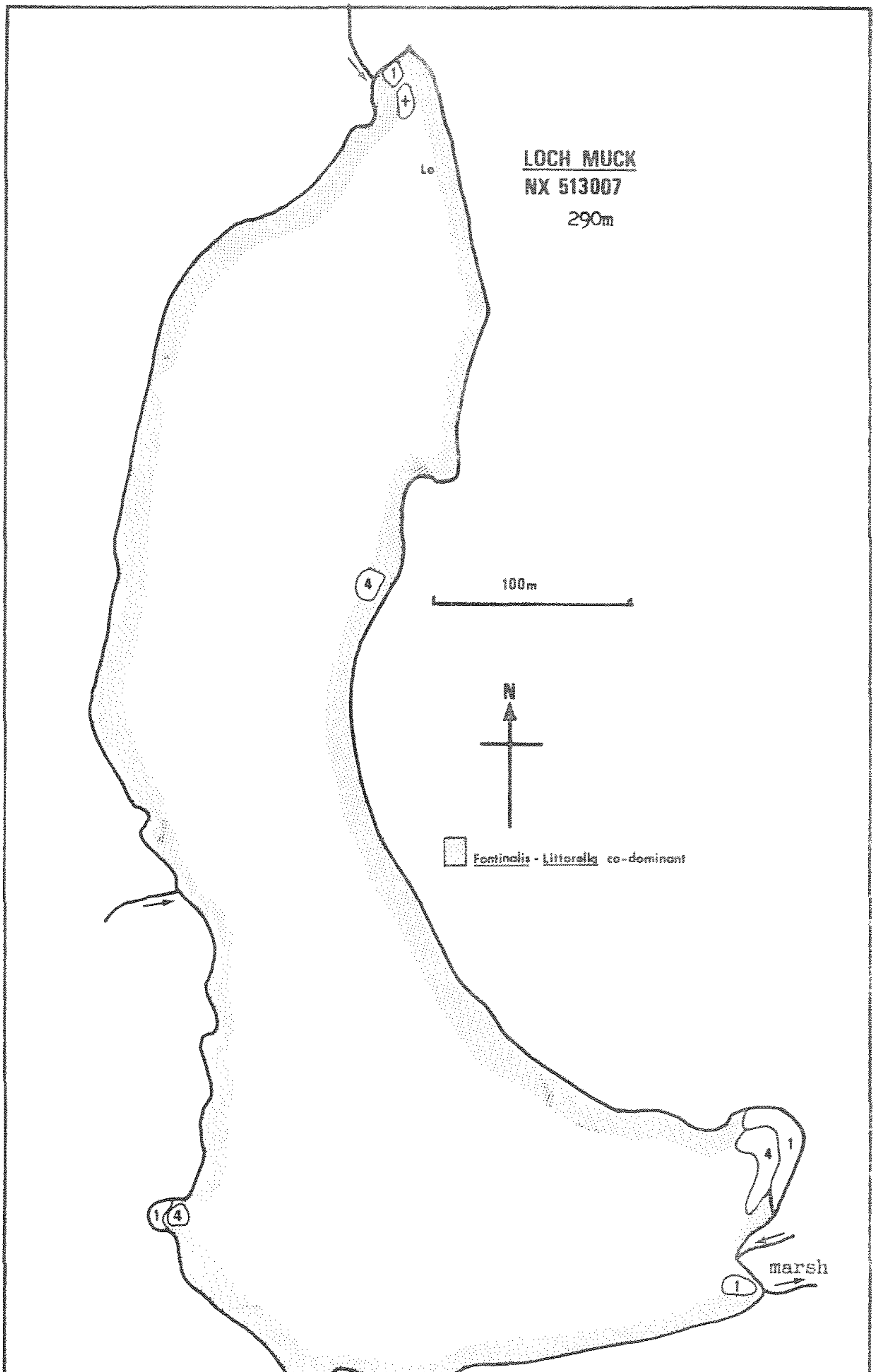

LOCH ENOCH
NX 445851
493m
Gull colony
on island
100 m
N
as indicated

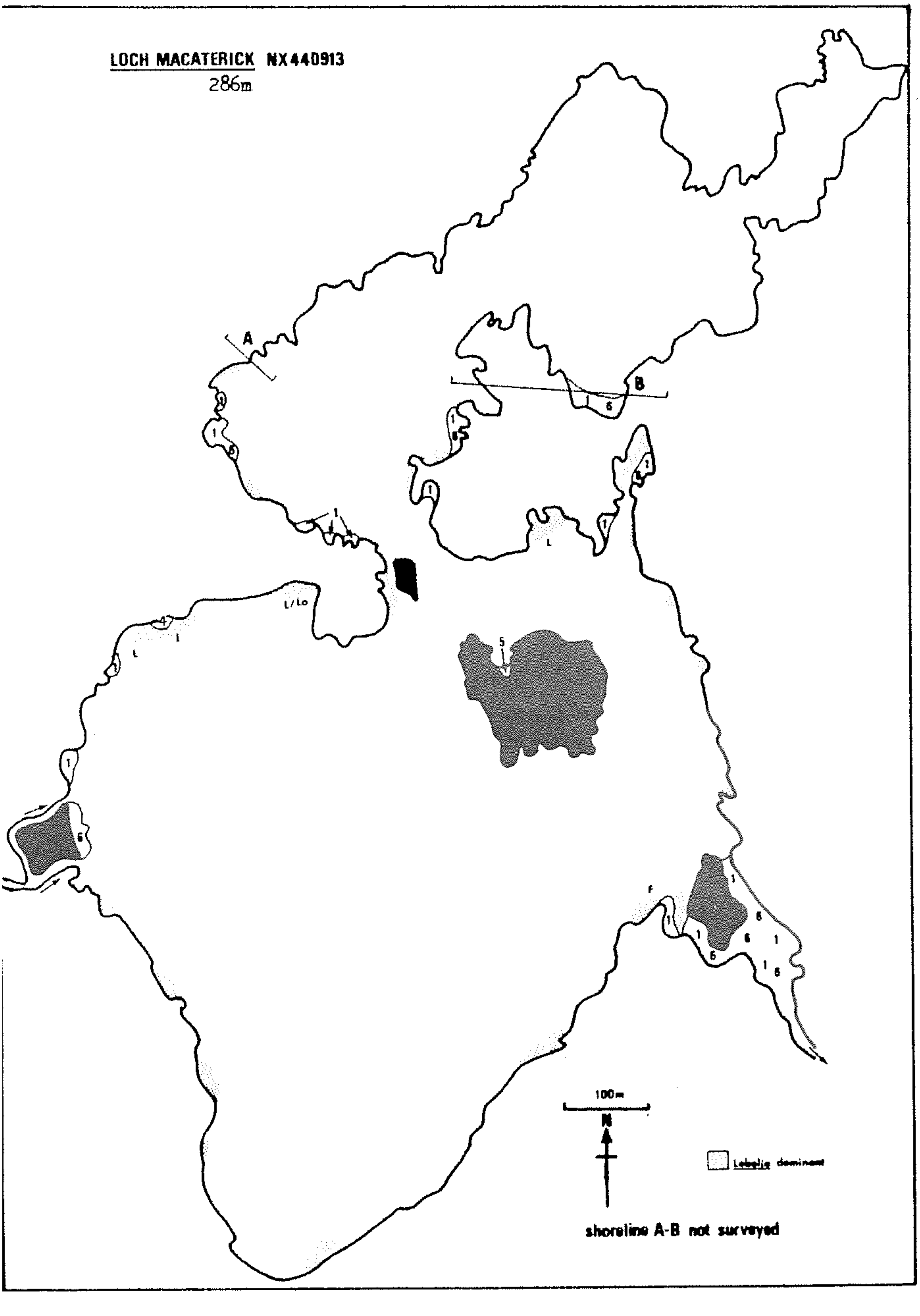


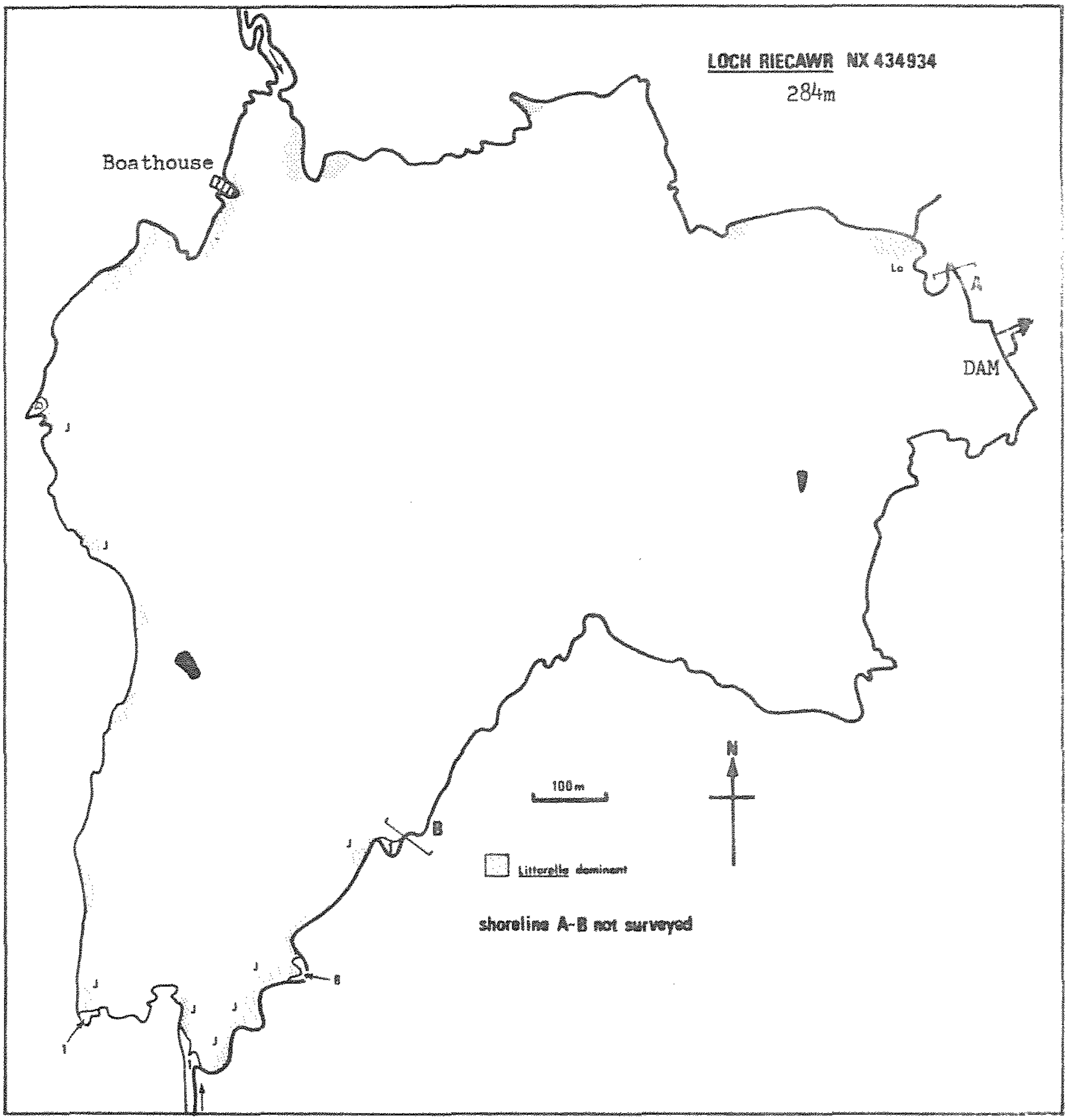
NB See Figures 3 & 4 for more detailed data

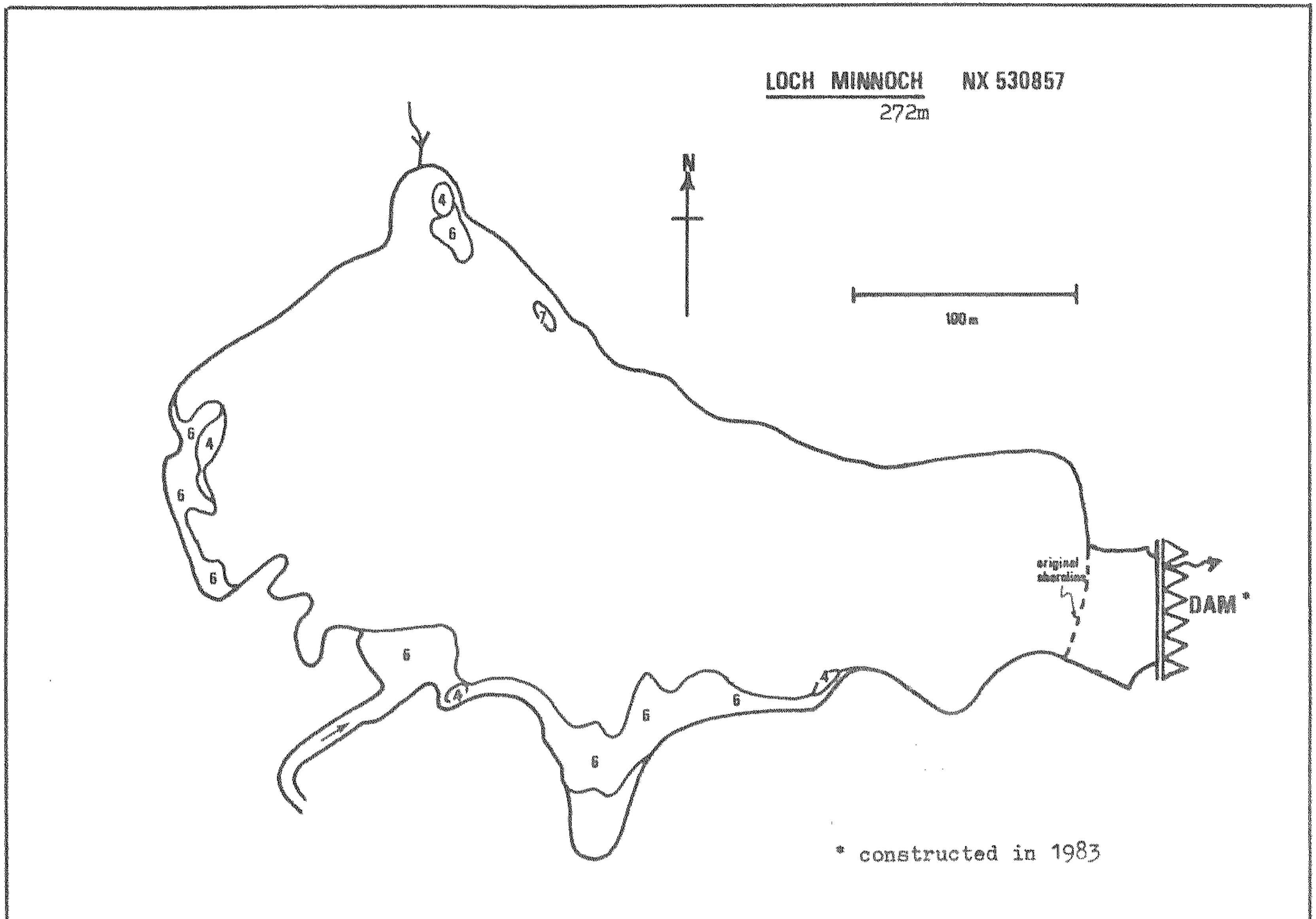

Lobelia dominant except where otherwise indicated
100m
N
LONG LOCH OF GLENHEAD NX 446808
298m
marsh
4


ROUND LOCH OF GLENHEAD NX 450804
295m
N
L
L
L
L
100m
J
J
J
Lobelia dominant except where otherwise indicated

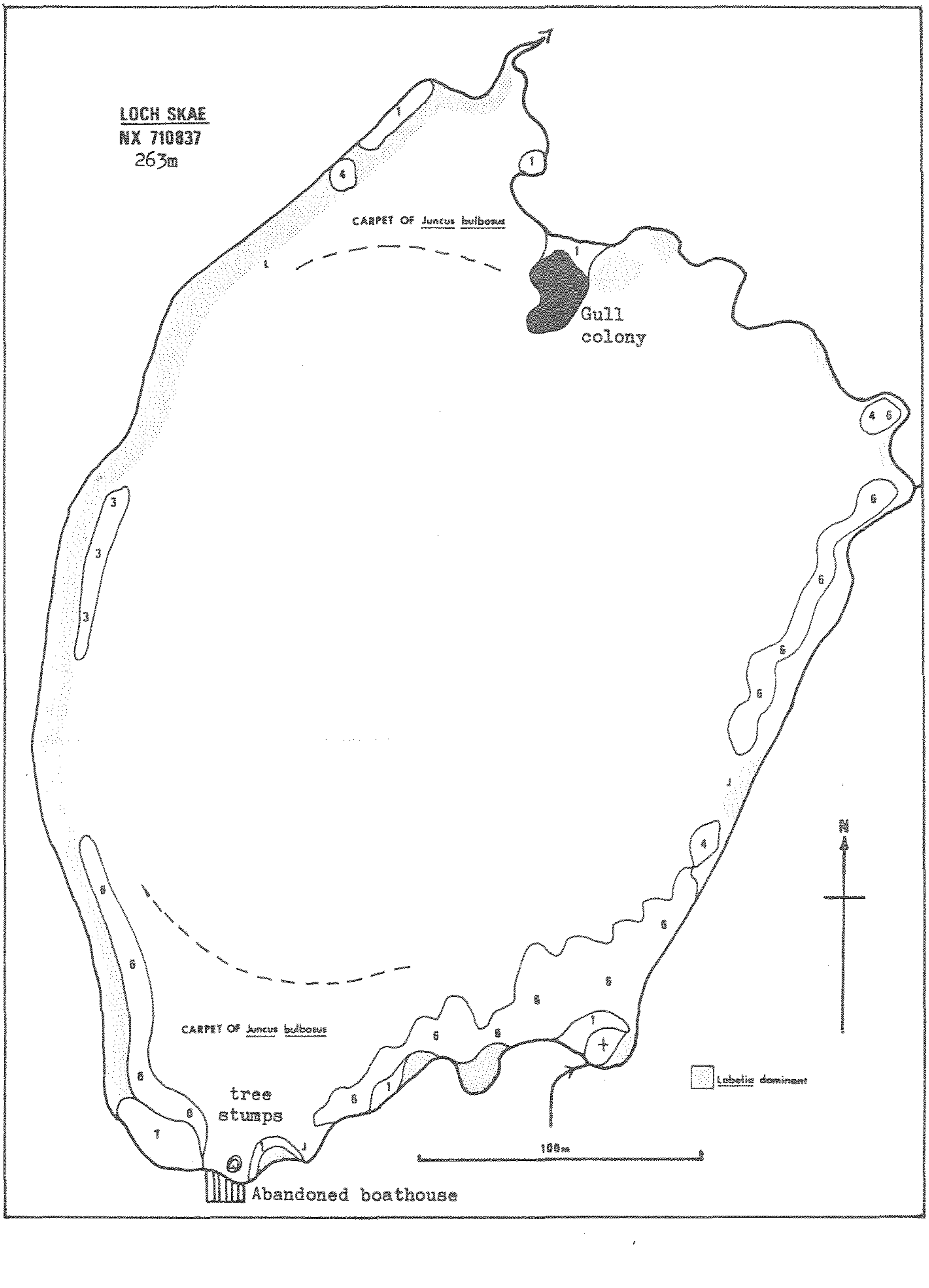

LOCH MUCK
NX 513007
290m
Lo
100m
N
Fontinalis - Littorella co-dominant
1
4
marsh
Boathouse

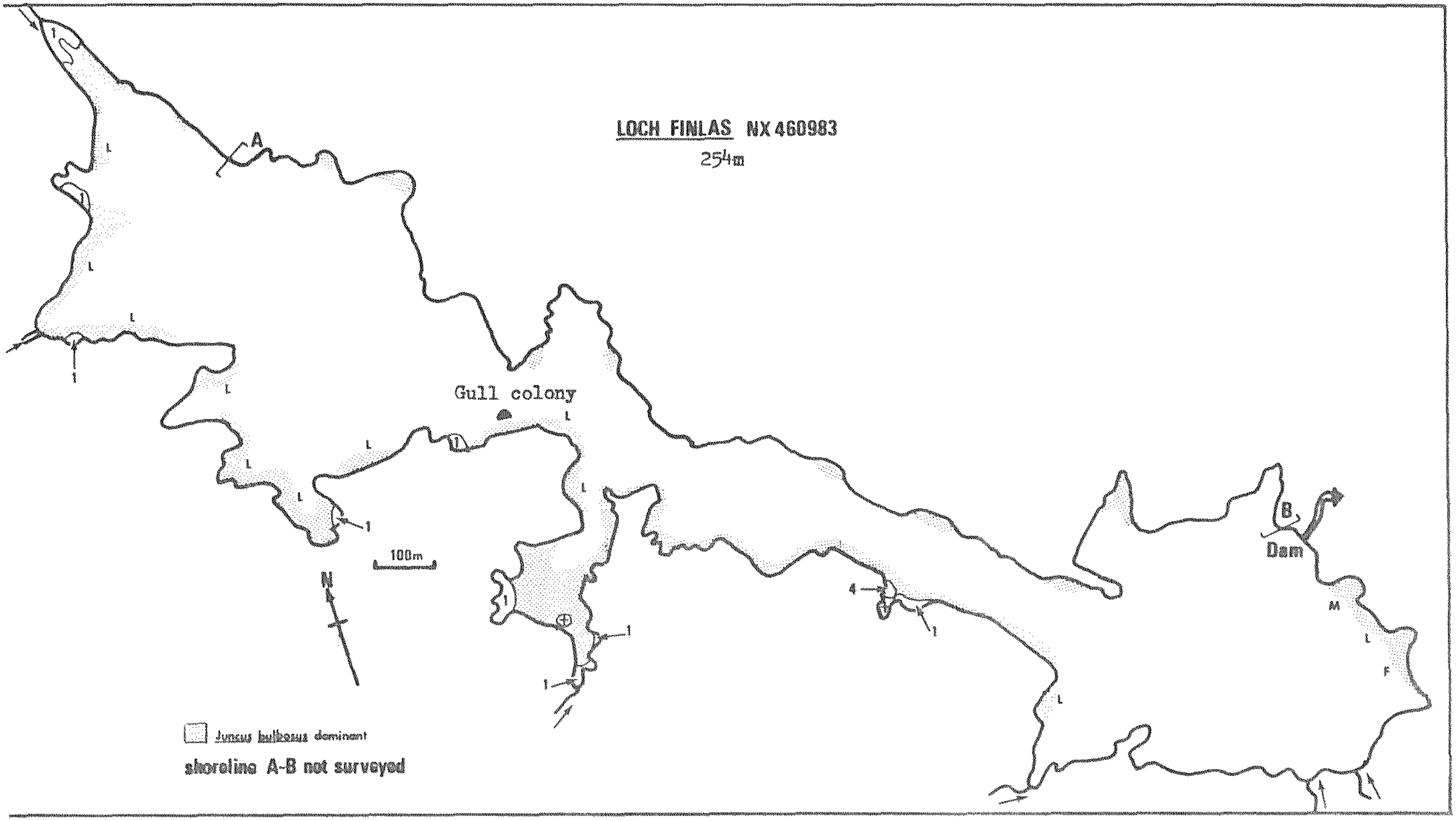

LOCH MACATERICK NX440913
286m
A
B
100m
N
Lobelia dominant
shoreline A-B not surveyed

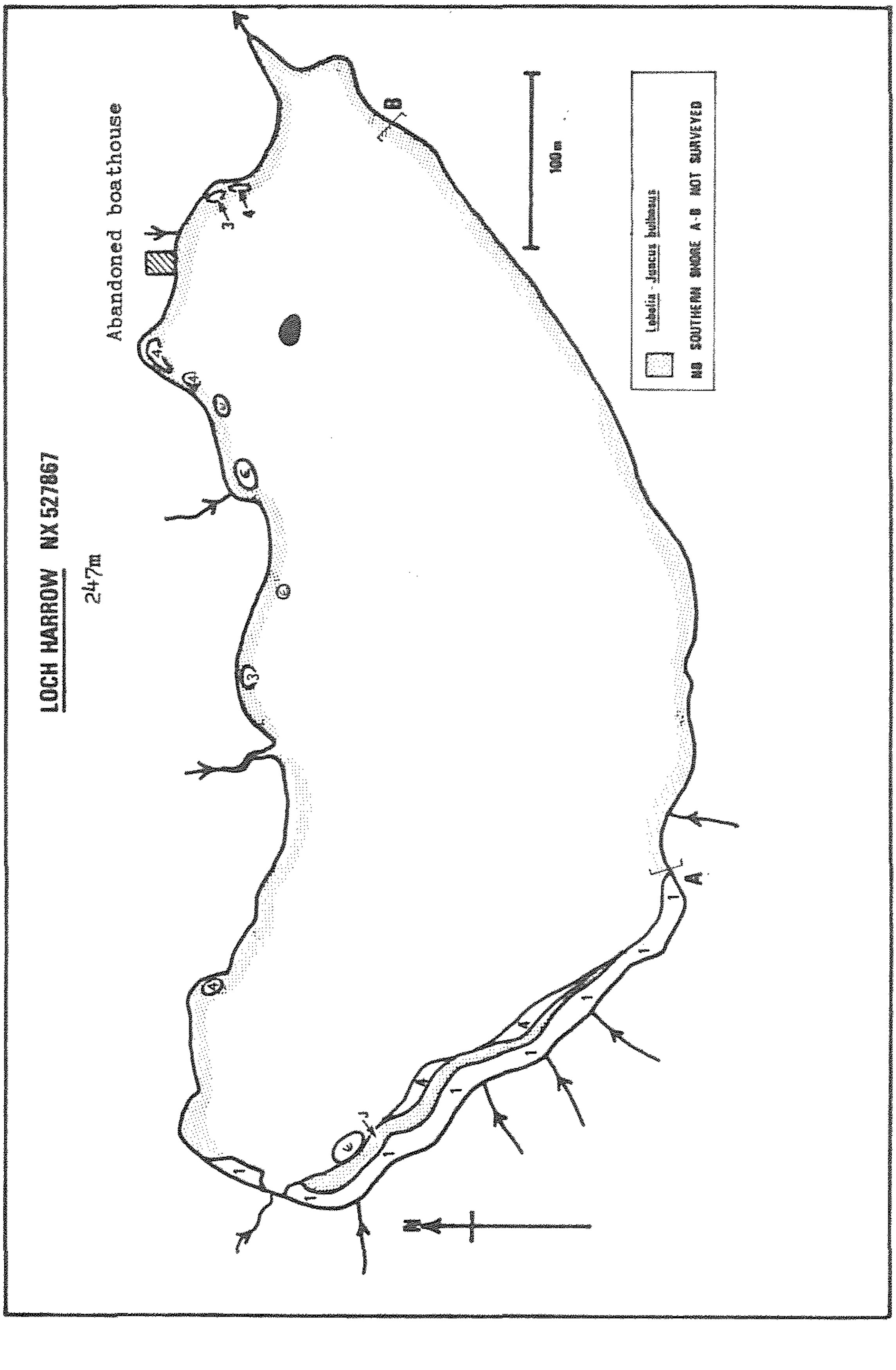

LOCH RIECAWR NX 434934
284m
Boathouse
DAM
A
B
Lo
J
100m
N
Littorella dominant
shoreline A-B not surveyed

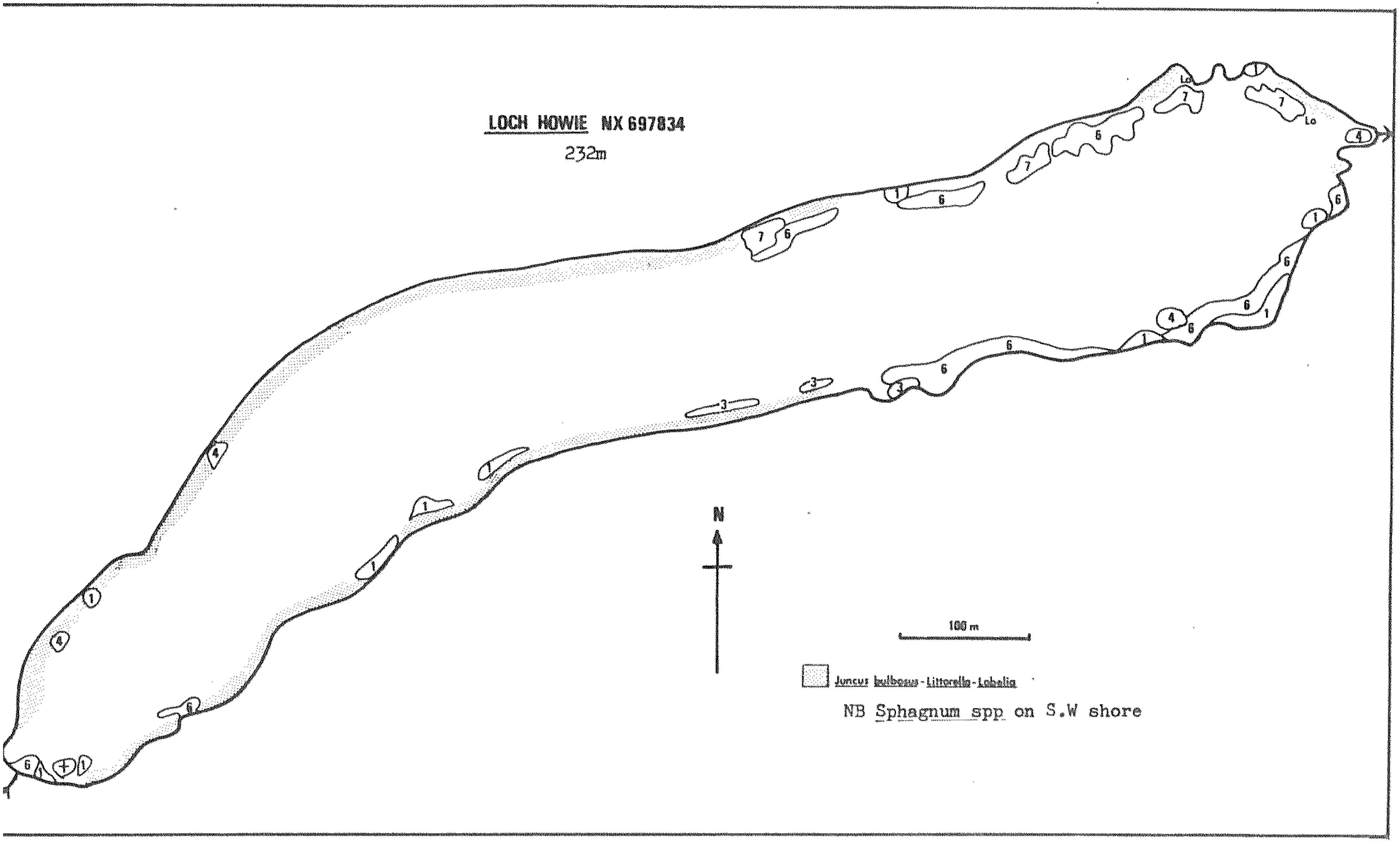


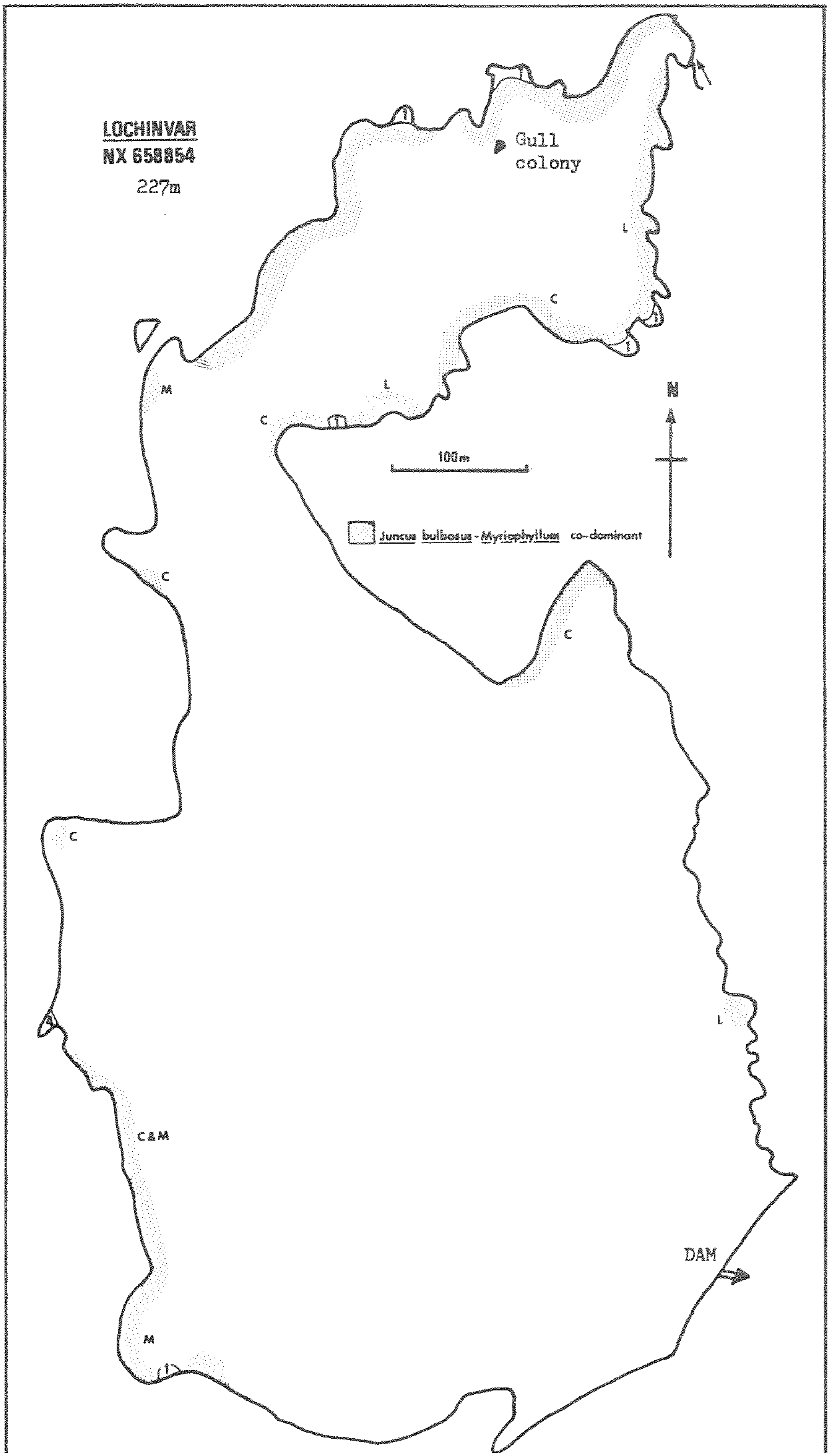
NB Submergent vegetation obscured by turbid water (secchi disc depth 0.2m) during survey

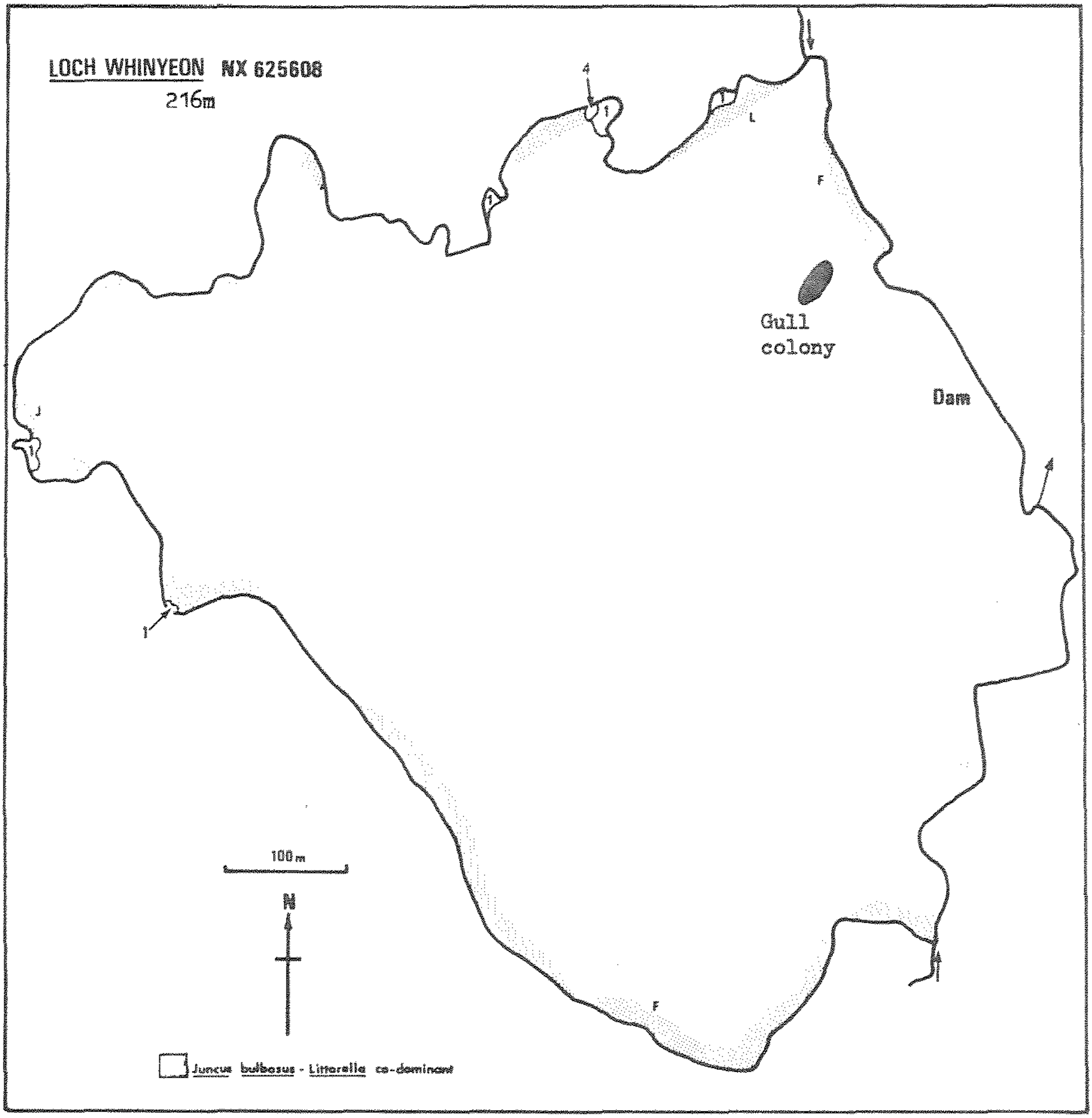

LOCH SKAE
NX 710837
263m
CARPET OF Juncus bulbosus
Gull colony
CARPET OF Juncus bulbosus
tree stumps
Abandoned boathouse
N
Lobelia dominant
100m


LOCH FINLAS NX 460983
254m
A
B
Dam
Gull colony
100m
N
Juncus bulbosus dominant
shoreline A-B not surveyed


LOCH HARROW NX 527867
247m
Abandoned boathouse
100m
Lobelia - Juncus bulbosus
NB SOUTHERN SHORE A-B NOT SURVEYED
A
B

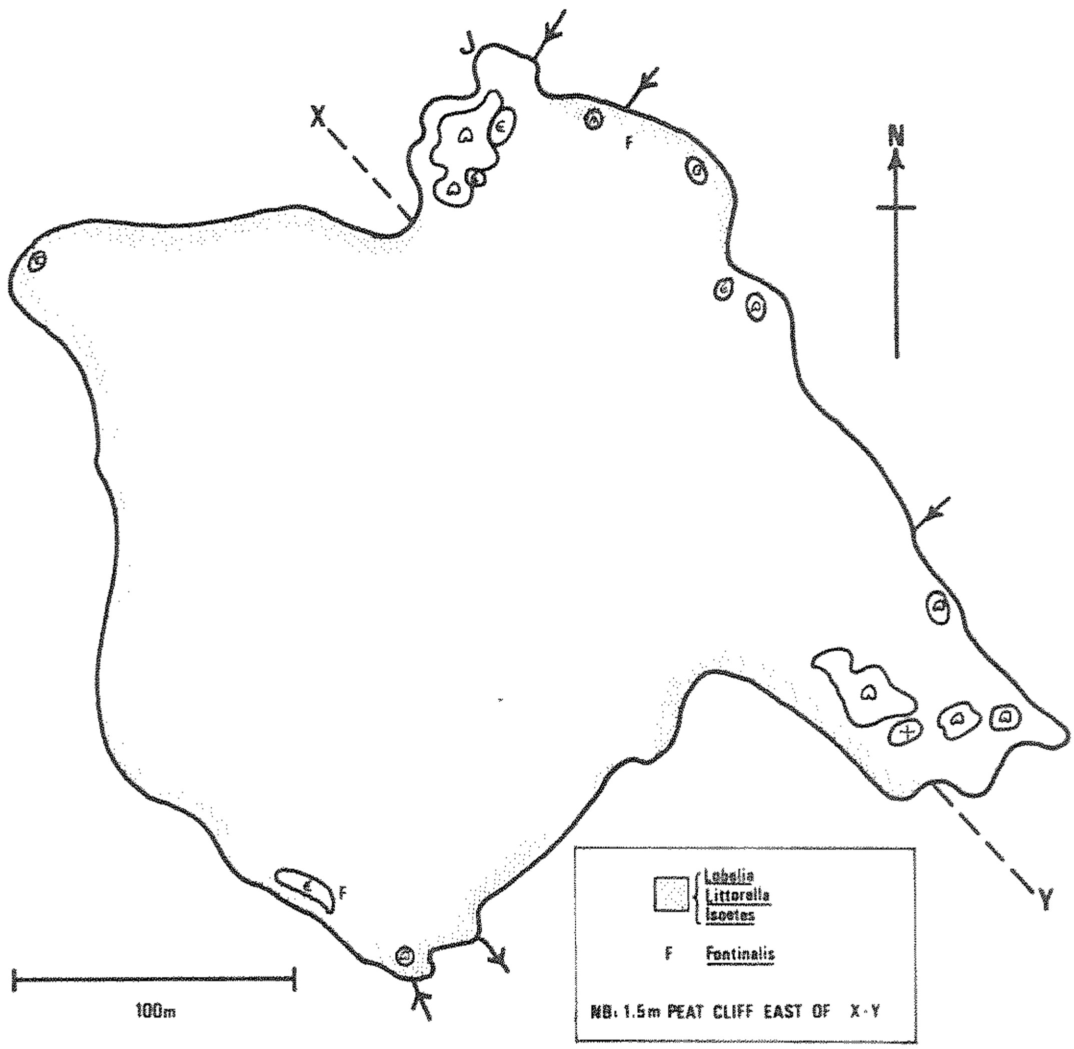

LOCH HOWIE NX 697834
232m
N
100 m
Juncus bulbosus - Littorella - Lobelia
NB Sphagnum spp on S.W shore
Lo
Lo

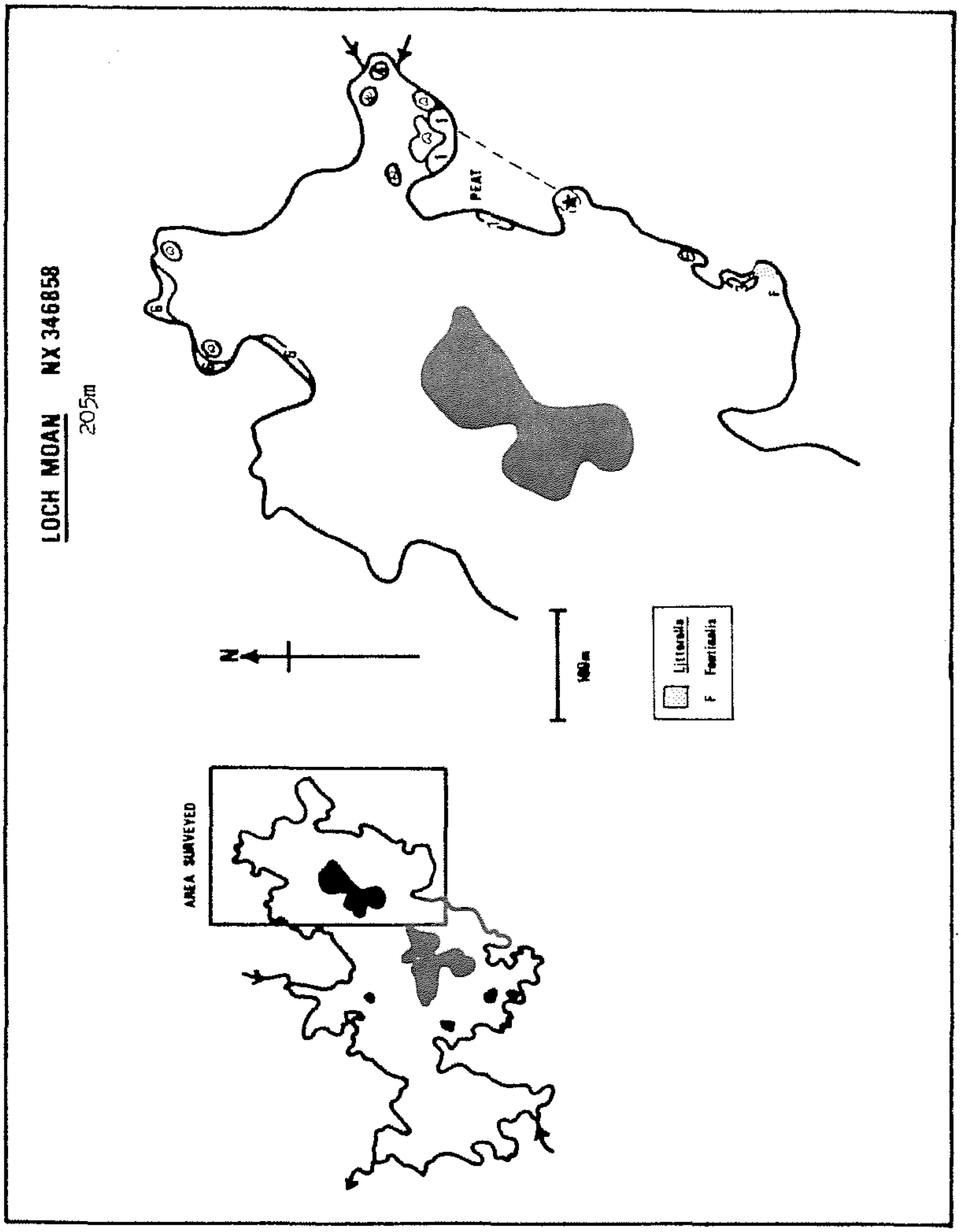

LOCHINVAR
NX 658854
227m
Gull
colony
N
100m
Juncus bulbosus - Myriophyllum co-dominant
C
L
M
C&M
DAM

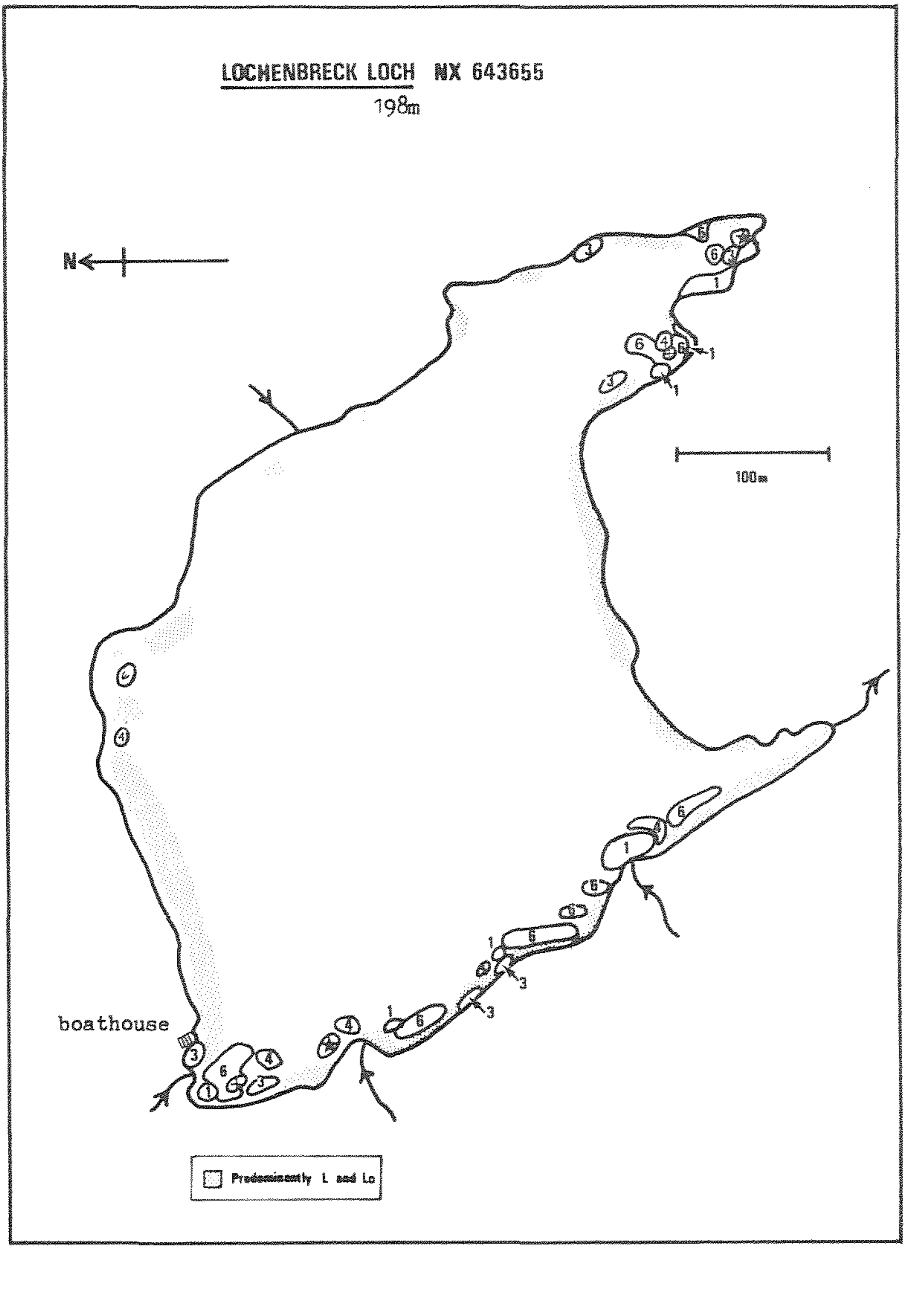

LOCH WHINYEON NX 625608
216m
4
1
1
1
L
F
1
Gull
colony
Dam
J
1
1
100 m
N
F
Juncus bulbosus - Littorella co-dominant

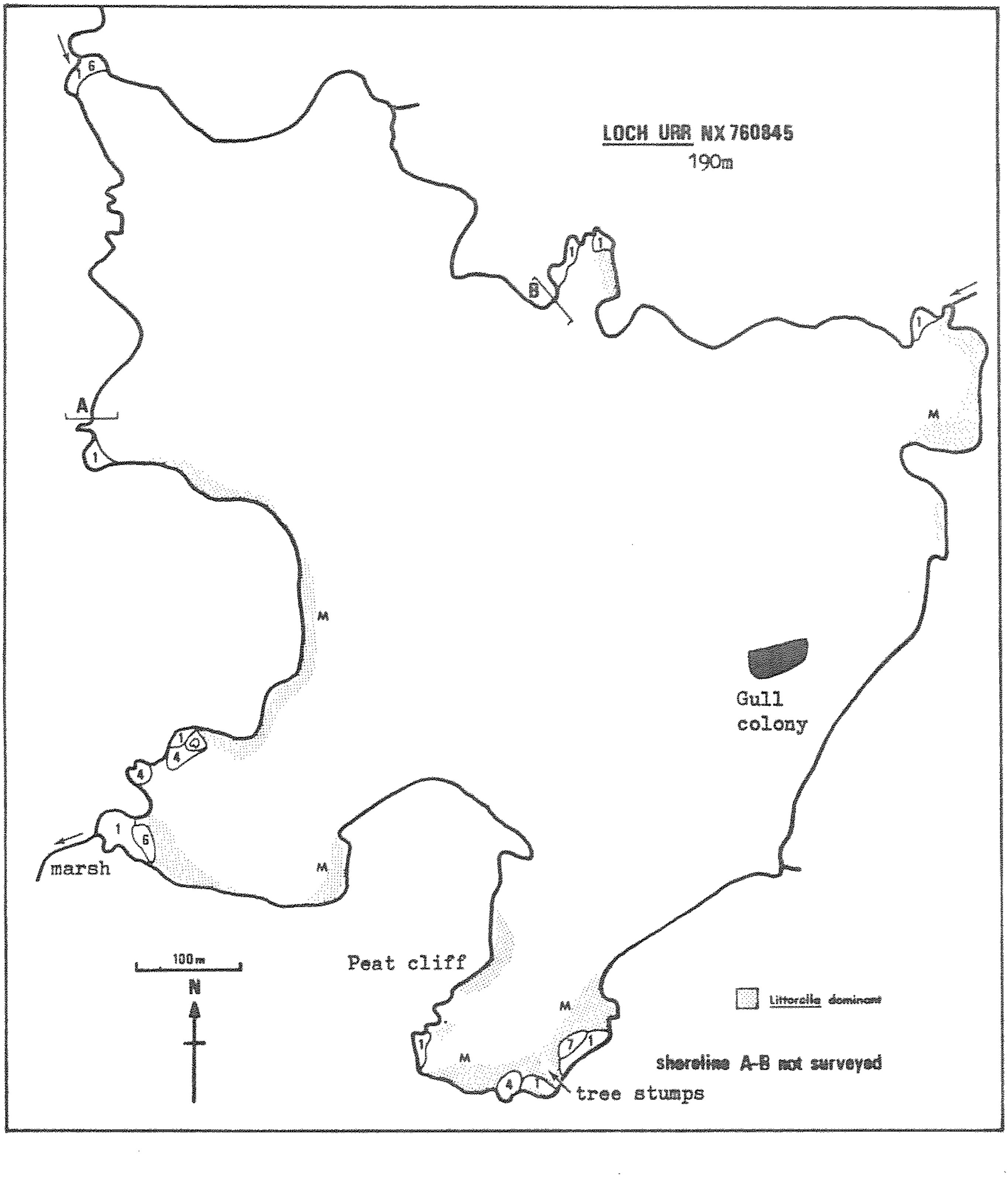
LOCH KIRRIEROCH NX 363865

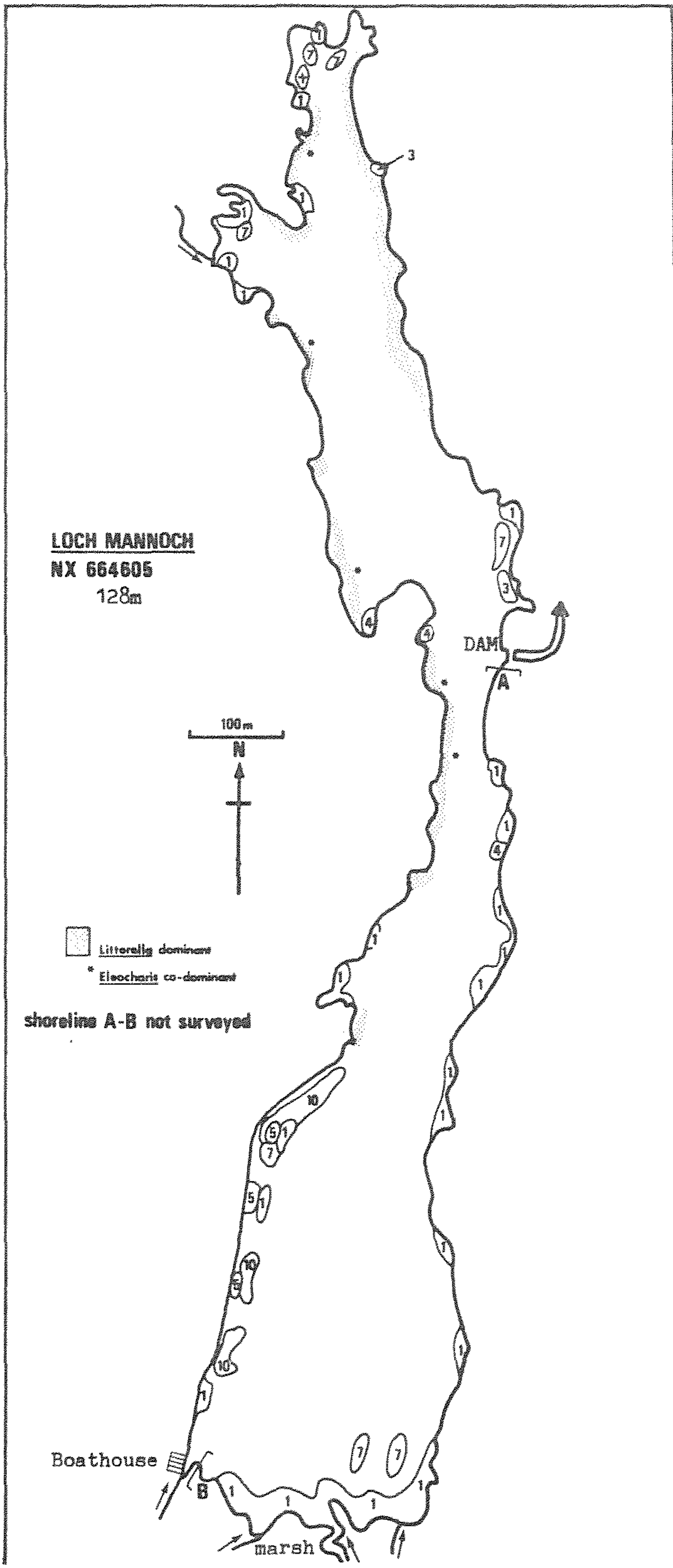
213m

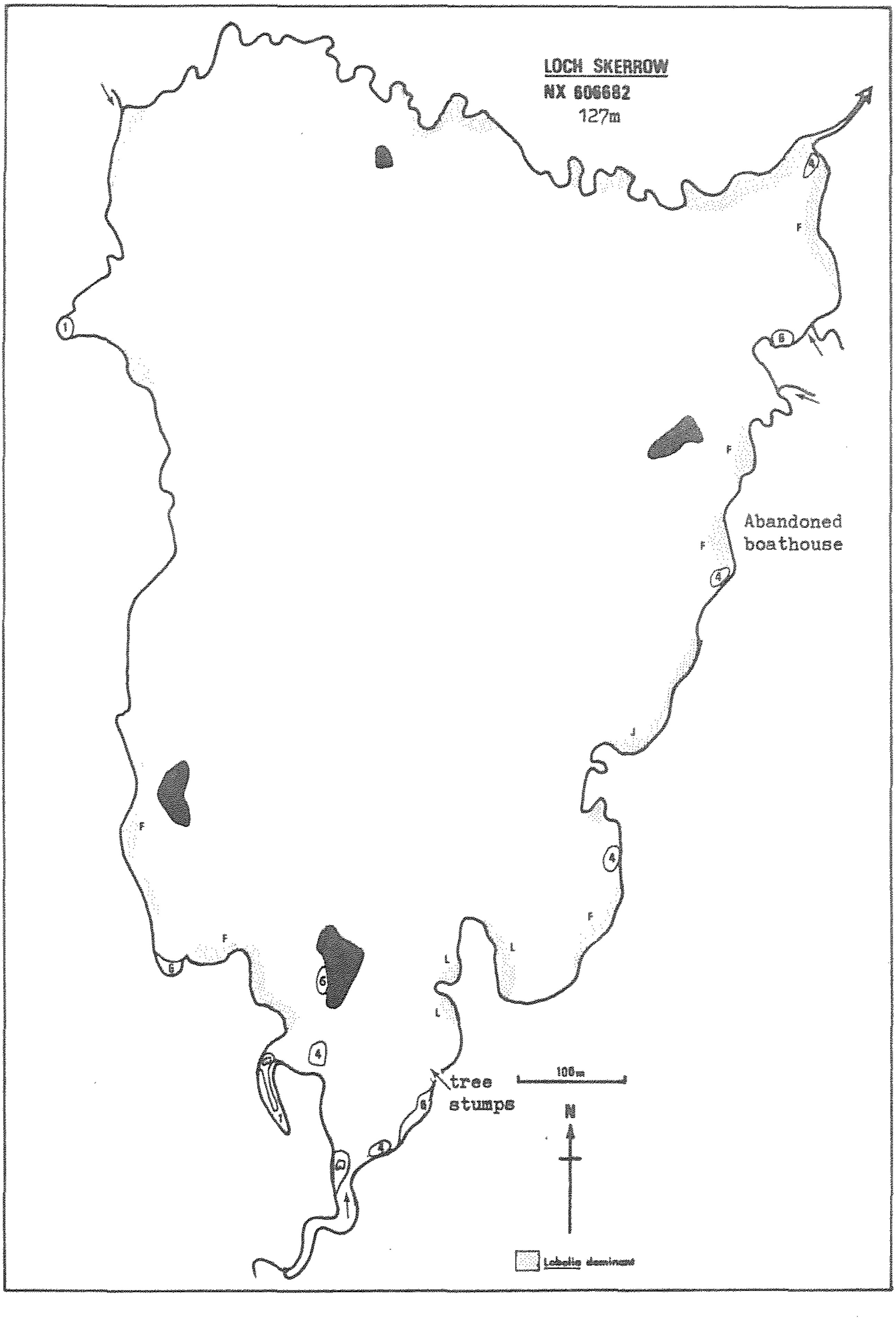


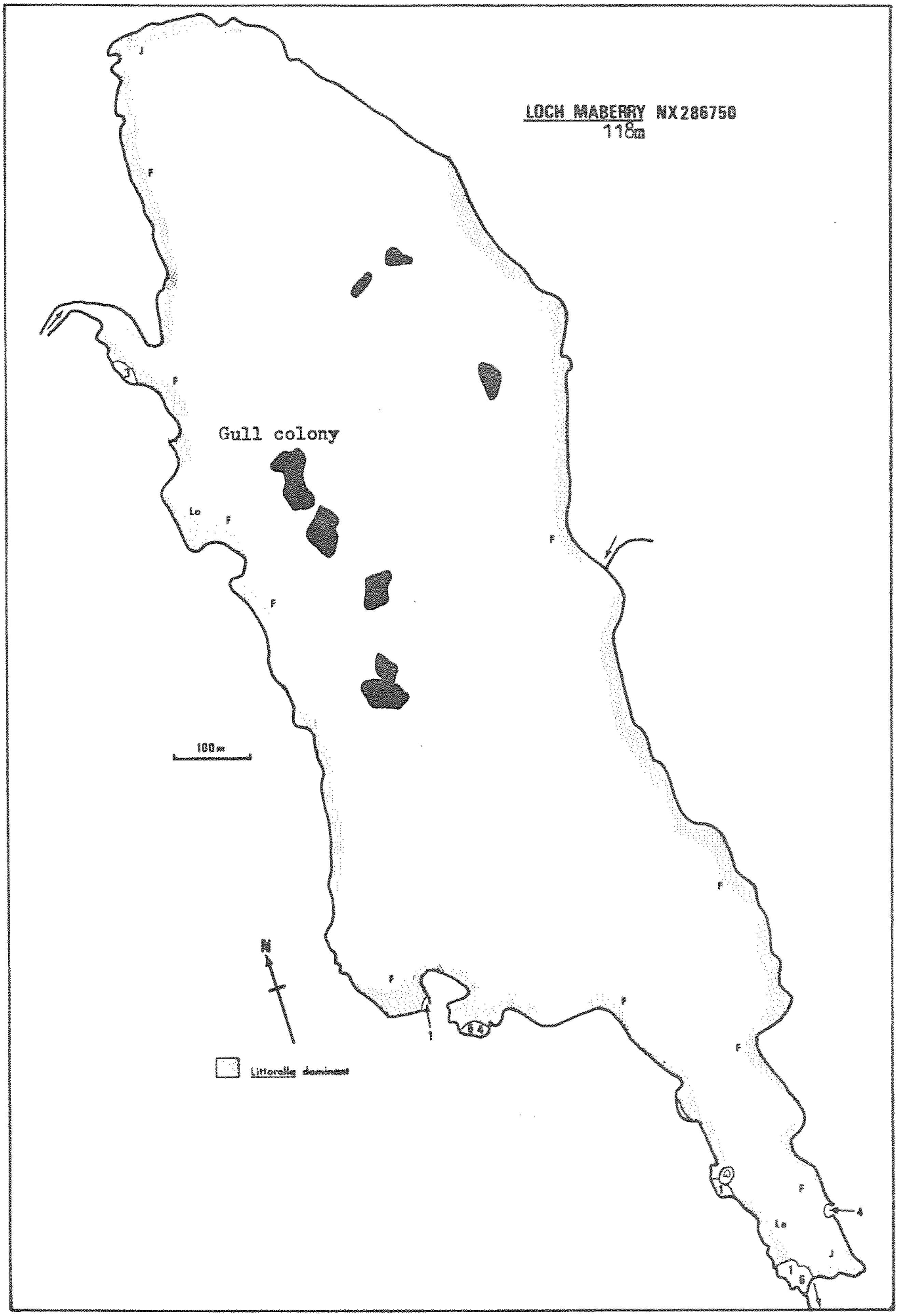

LOCH MOAN
NX 346858
205m
AREA SURVEYED
PEAT
N
100m
Littorella
F Fontinalis

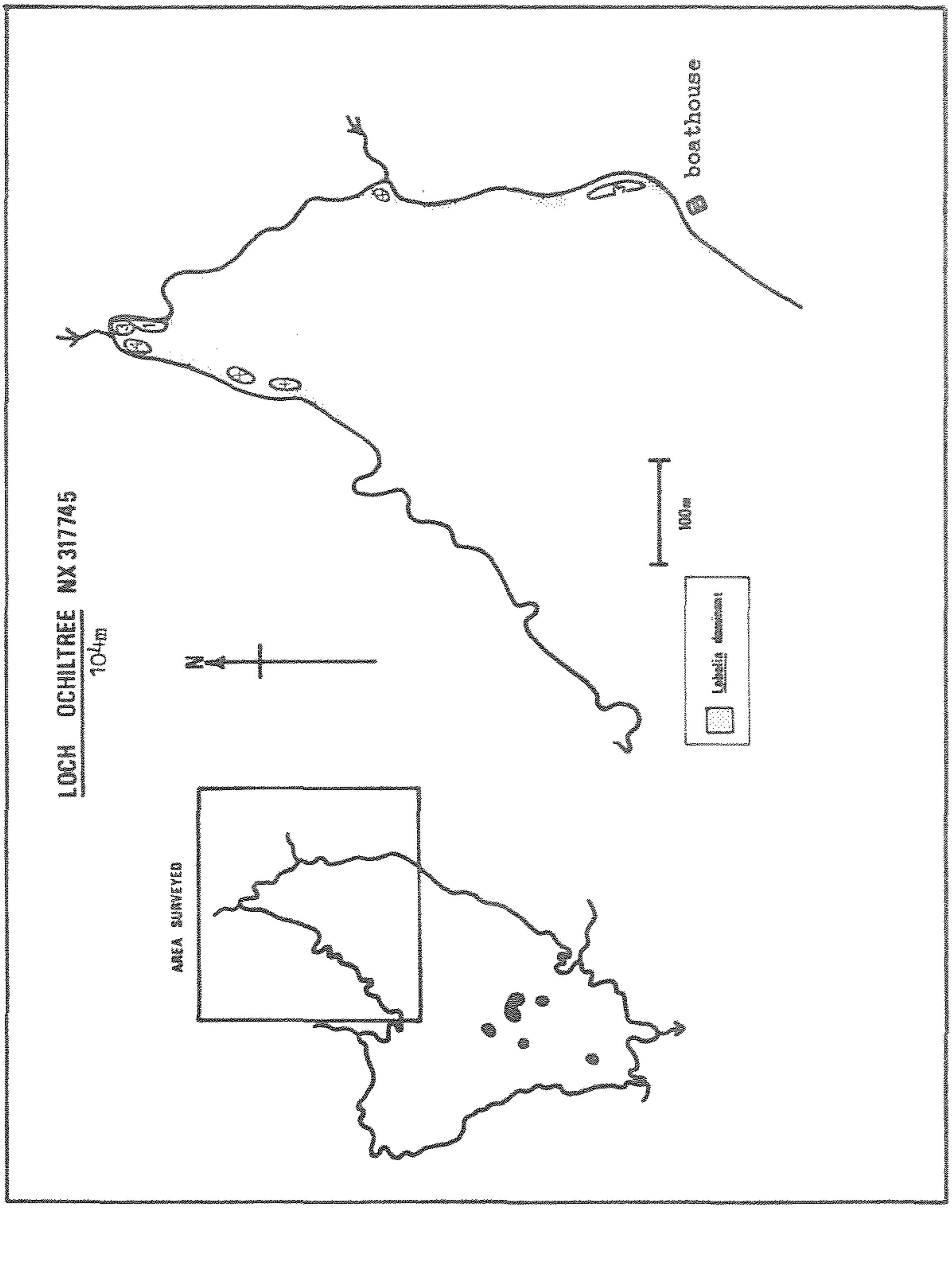

LOCHENBRECK LOCH NX 643655
198m
N
100m
boathouse
Predominantly L and Lo

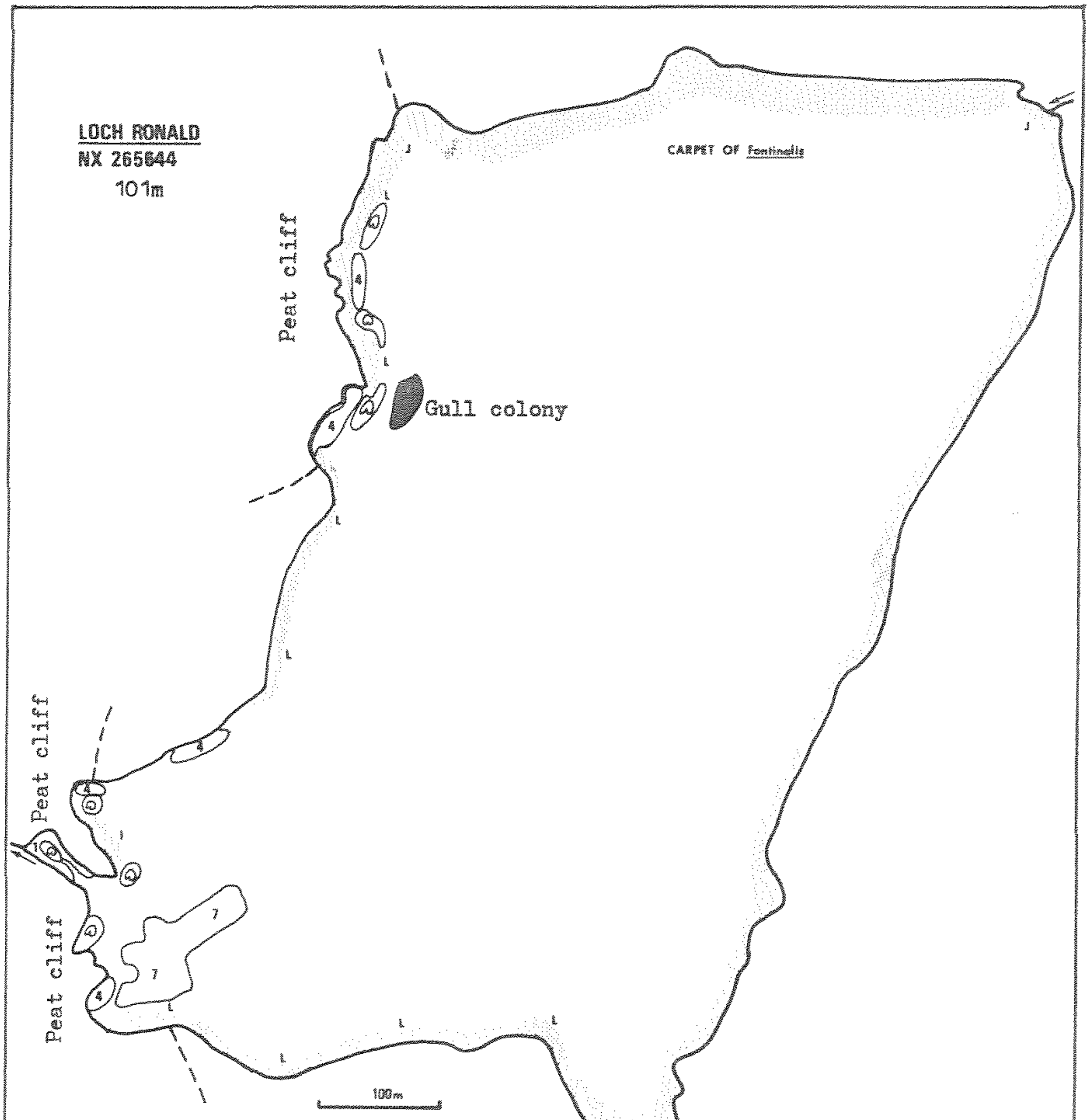

LOCH URR NX760845
190m
A
B
M
Gull colony
marsh
Peat cliff
100m
N
Littorella dominant
shoreline A-B not surveyed
tree stumps

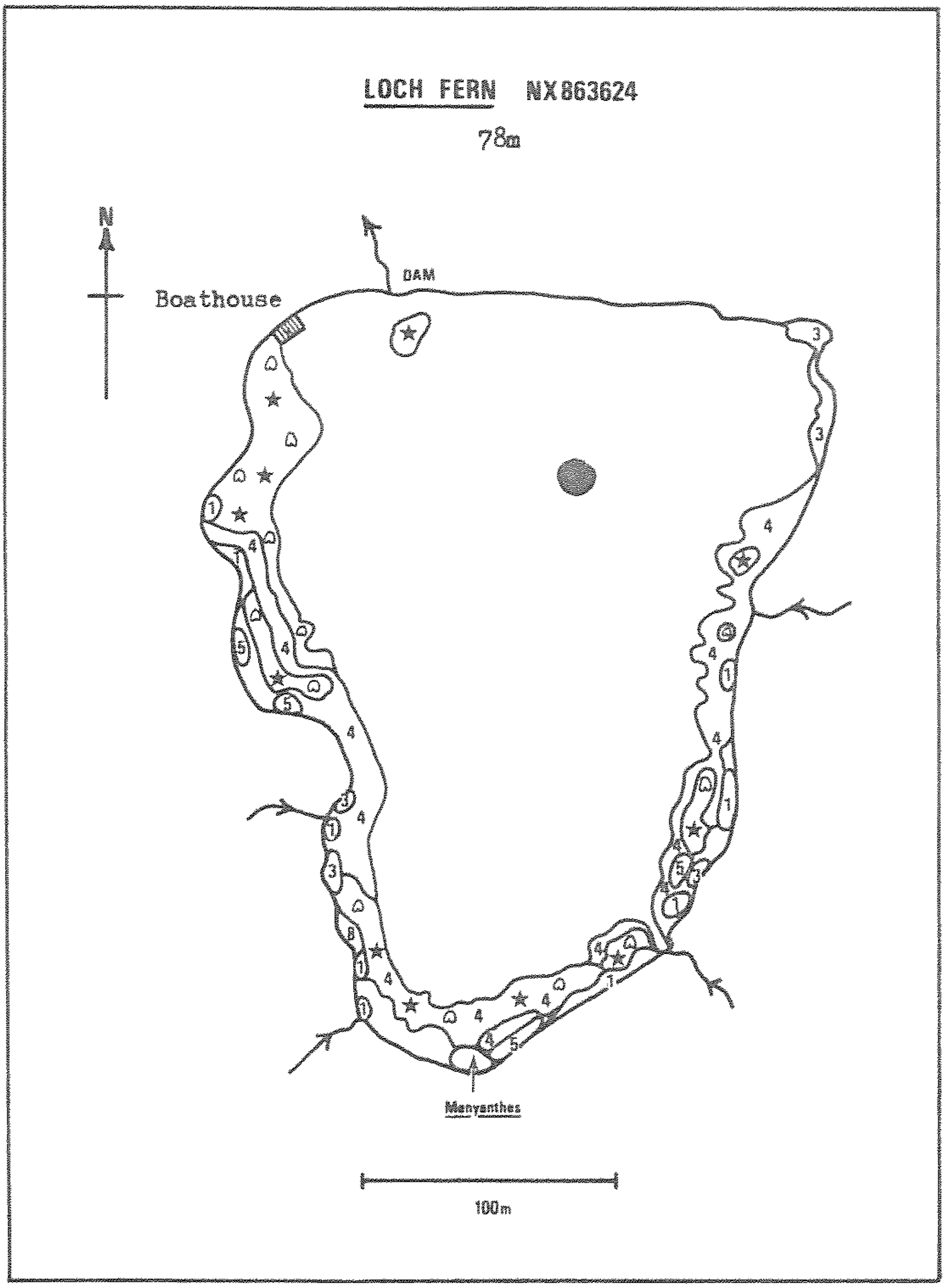

LOCH MANNOCH
NX 664605
128m
100m
N
DAM
A
B
Littorella dominant
* Eleocharis co-dominant
shoreline A-B not surveyed
Boathouse
marsh

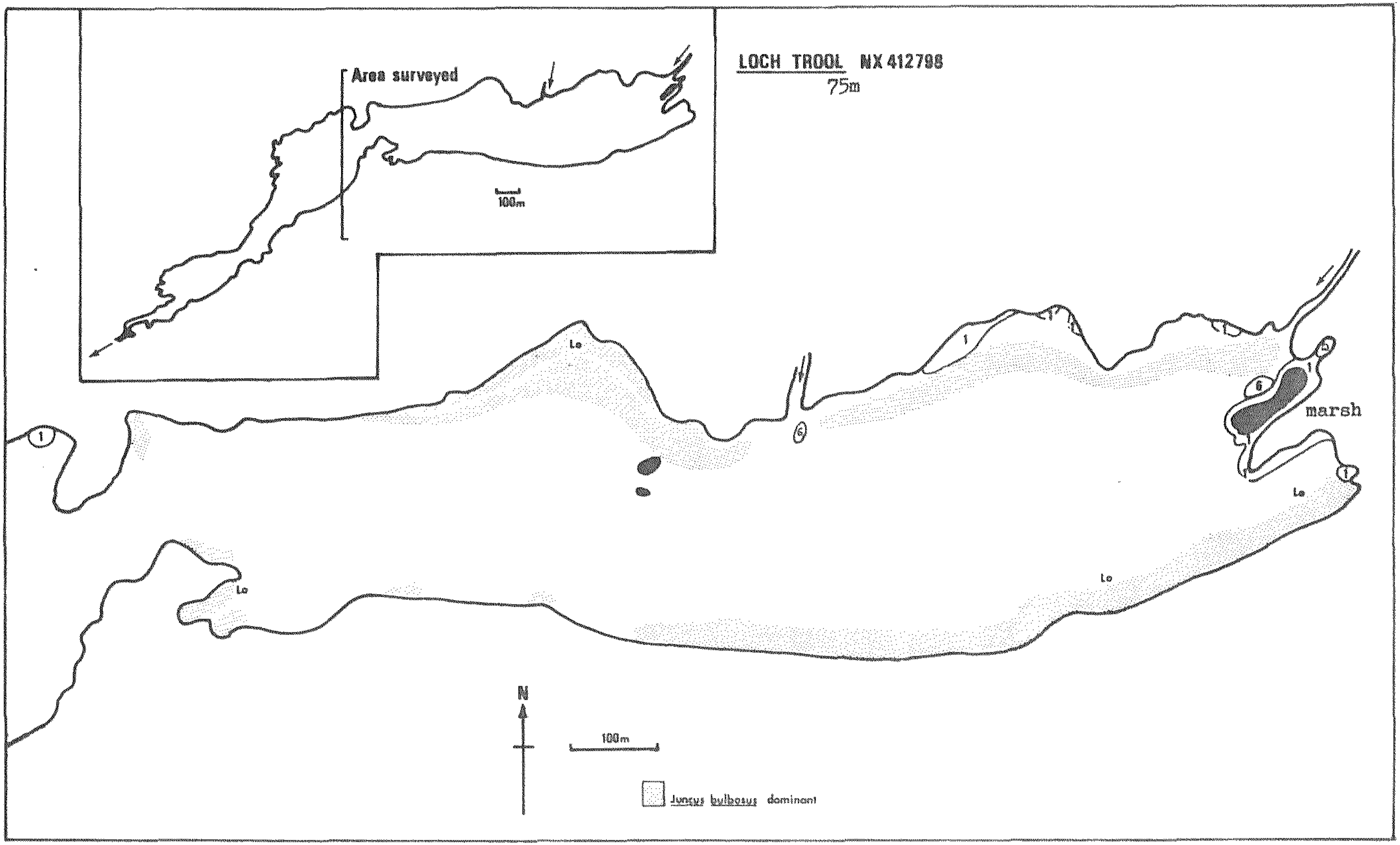

LOCH SKERROW
NX 606682
127m
Abandoned
boathouse
tree
stumps
100m
N
Lobelia dominant


LOCH MABERRY NX286750
118m
Gull colony
100m
N
Littorella dominant
J
F
Lo
1
4
6

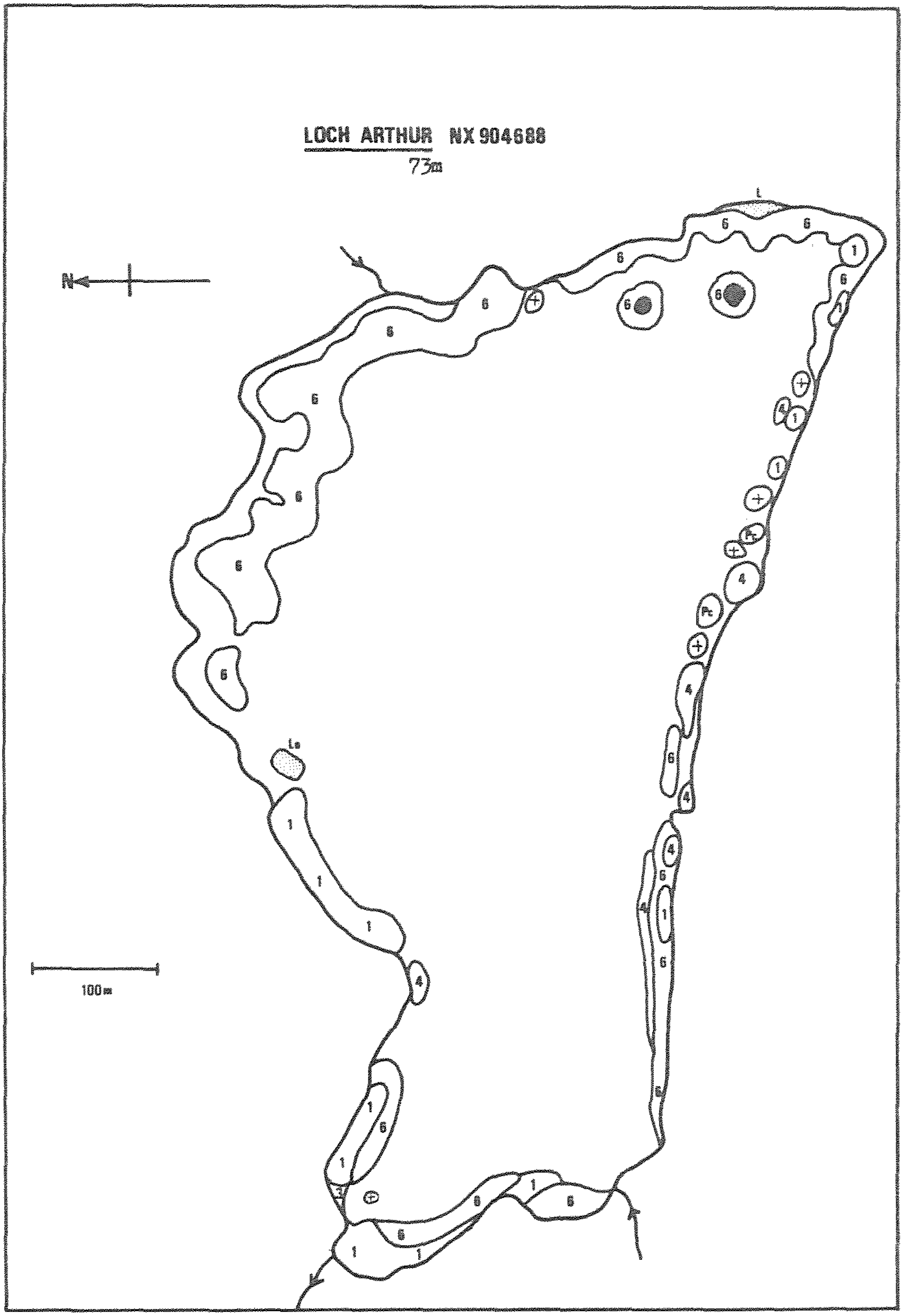

LOCH OCHILTREE NX 317745
10^4m
N
AREA SURVEYED
boathouse
100m
Lobelia dominant

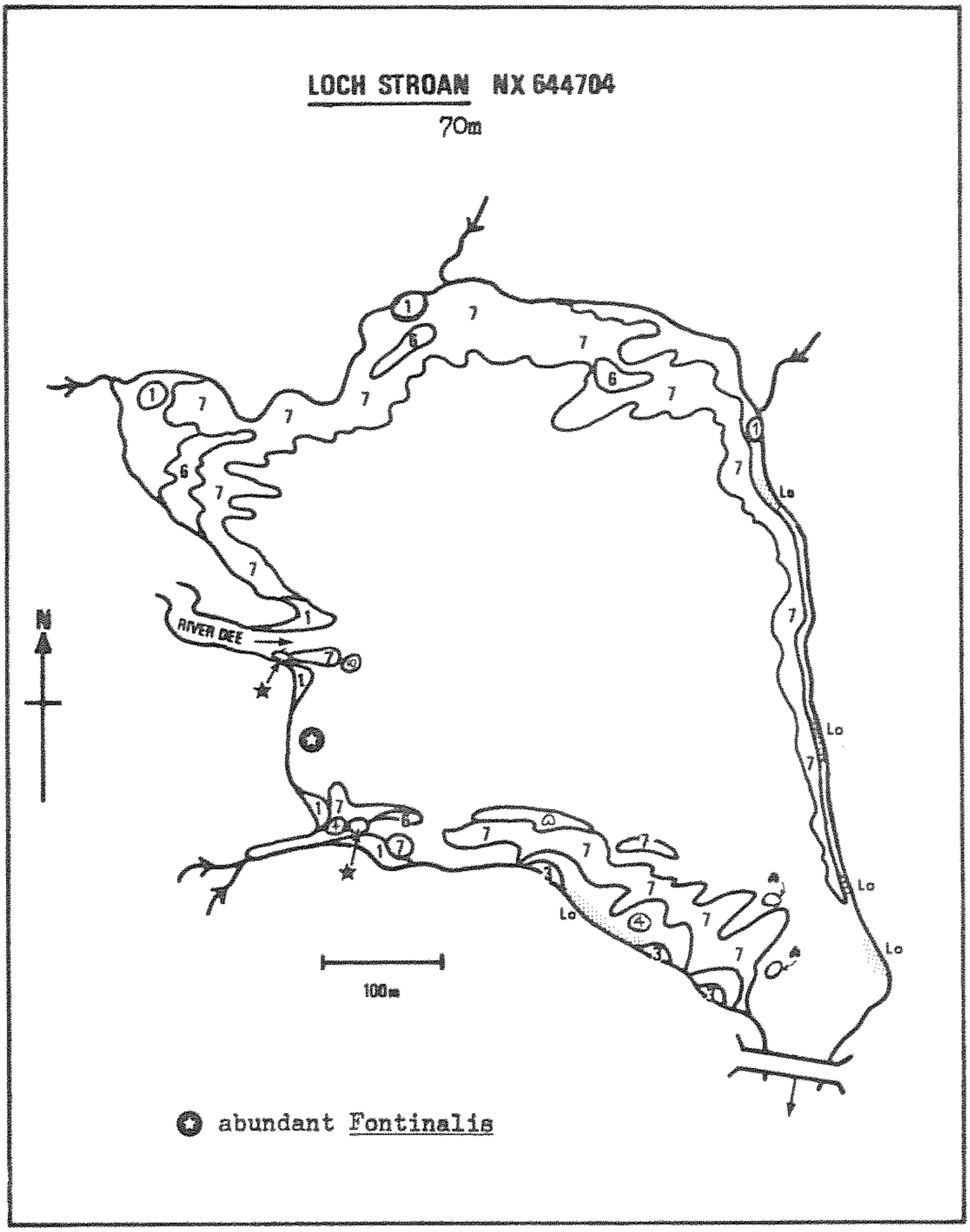

LOCH RONALD
NX 265644
101m
Peat cliff
Gull colony
CARPET OF Fontinalis
Peat cliff
Peat cliff
100m
Littorella-Fontinalis co-dominant

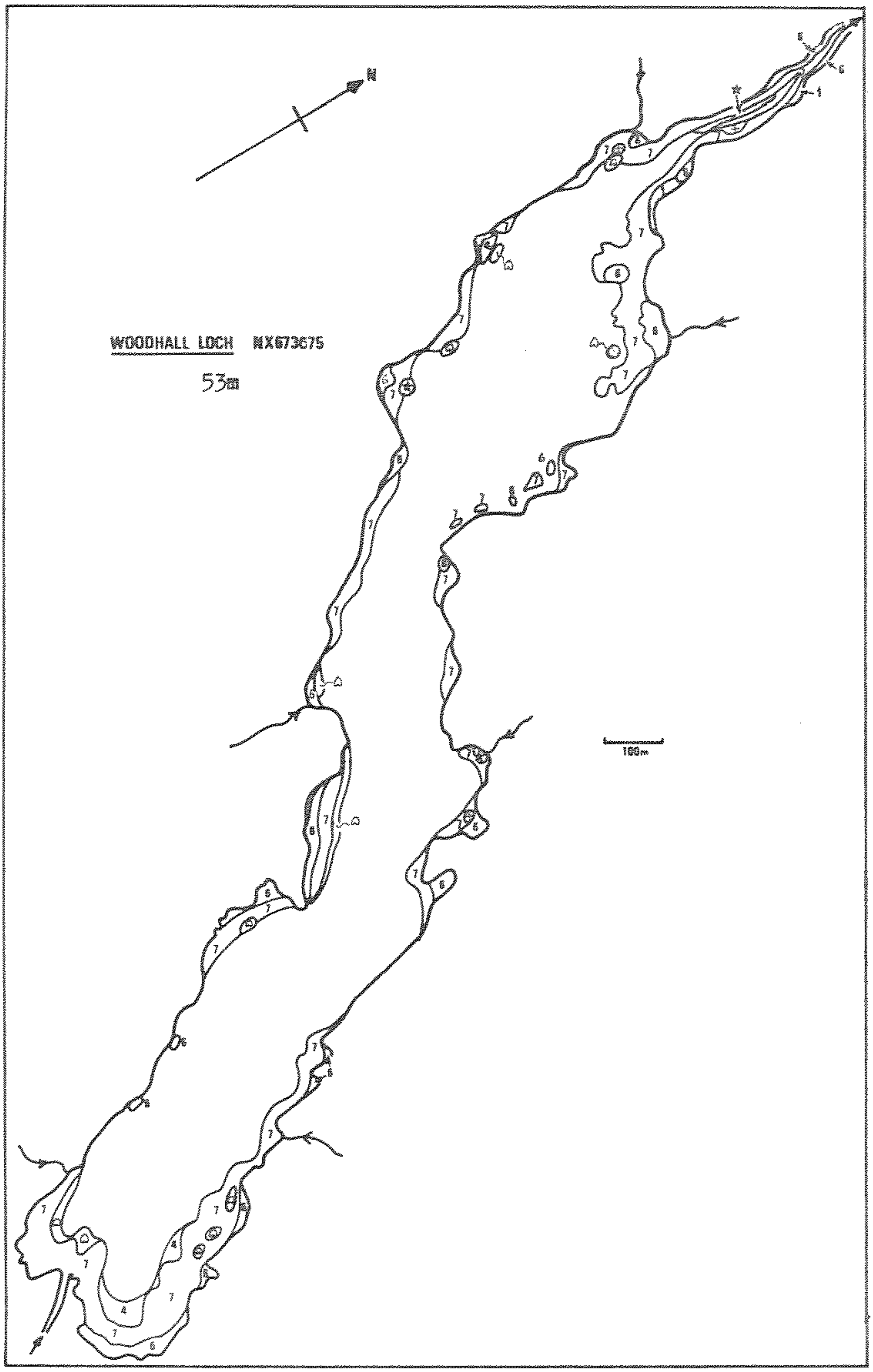

LOCH FERN NX863624
78m
N
DAM
Boathouse
Menyanthes
100m

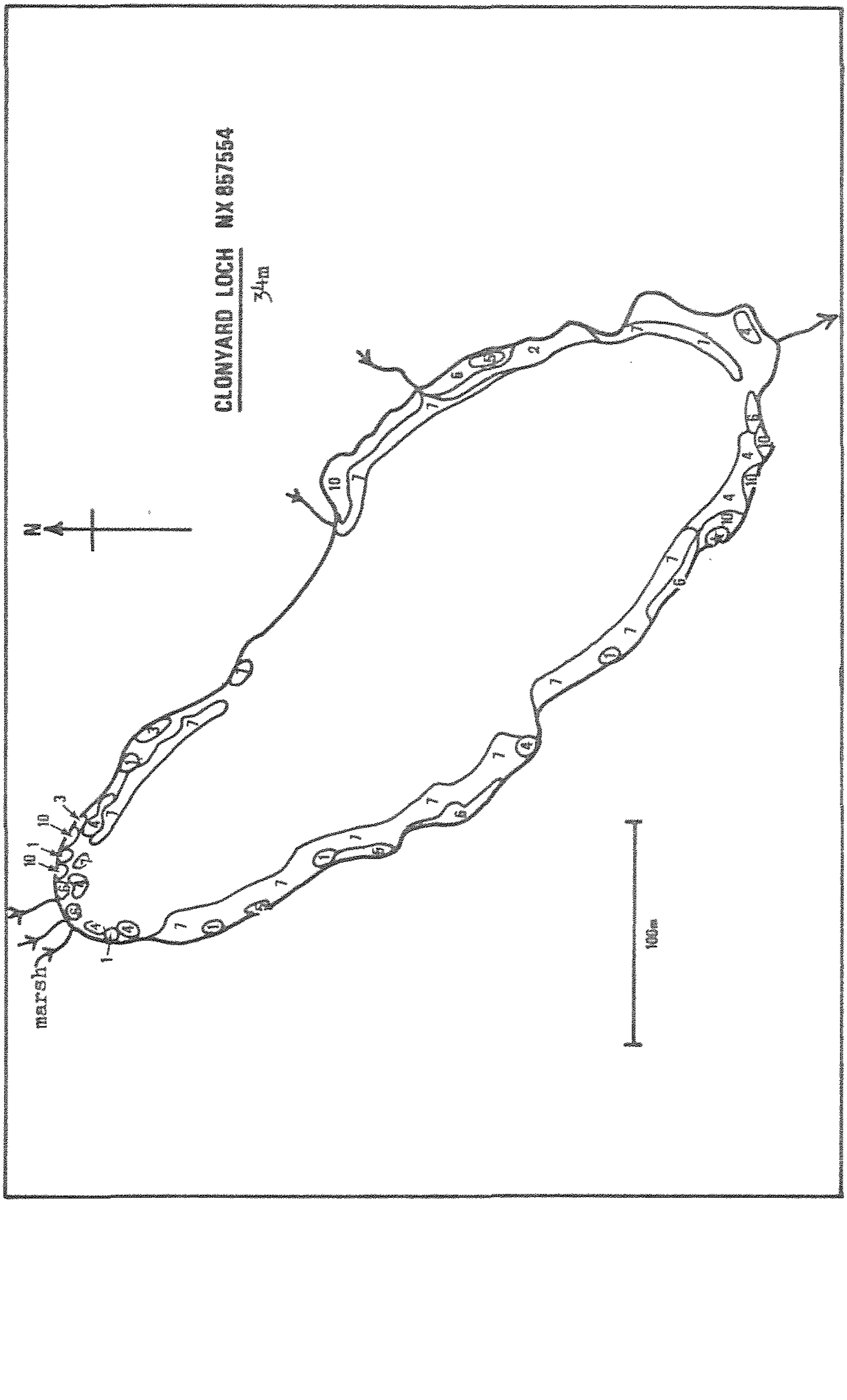


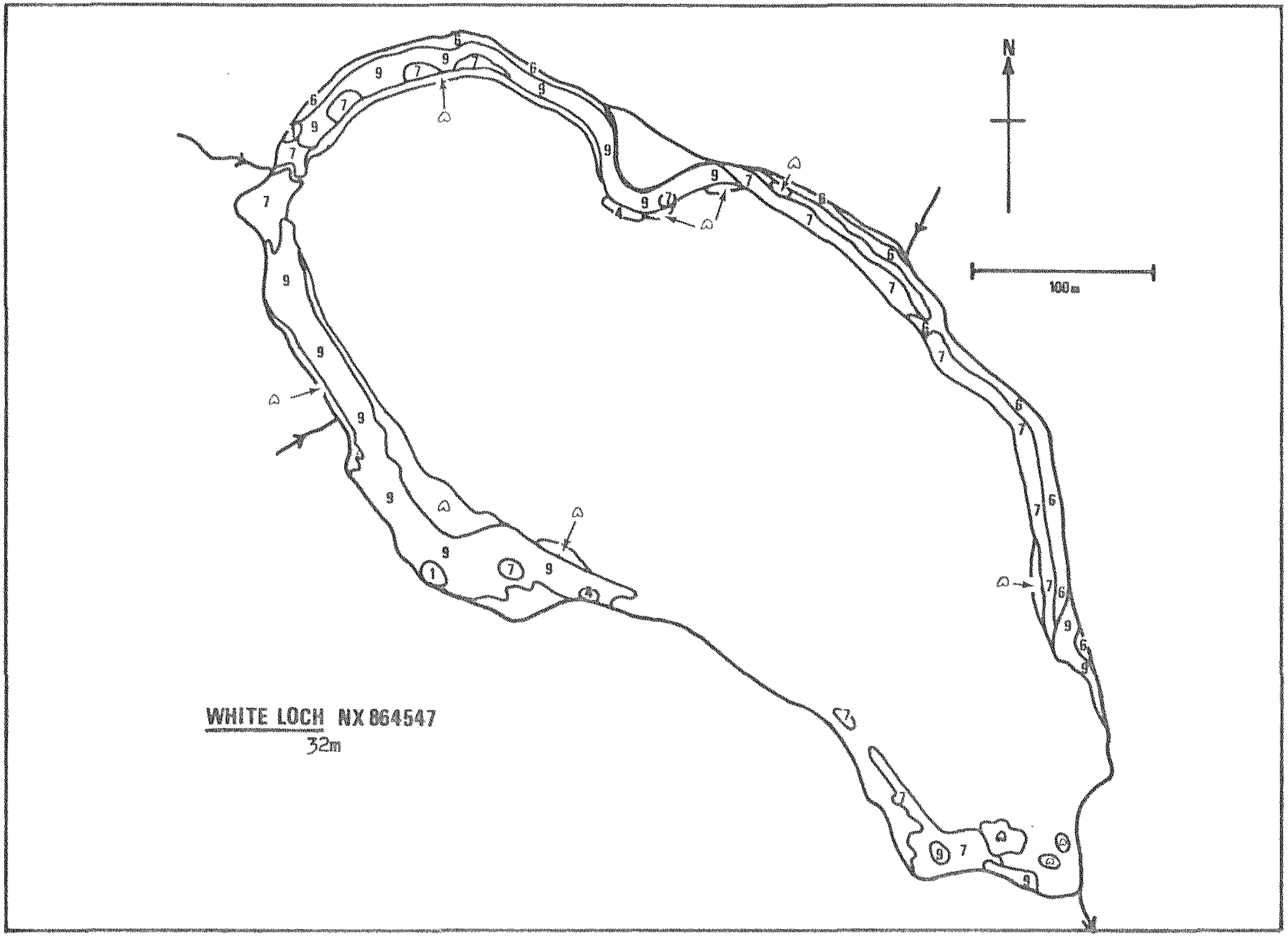
LOCH TROOL NX 412798
75m
Area surveyed
100m
marsh
Lo
1
6
N
100m
Juncus bulbosus dominant


LOCH ARTHUR NX 904688
73m
N
100m
L
Lo
Pc
6
1
4
3


LOCH STROAN NX 644704
70m
RIVER DEE
N
100m
Lo
abundant Fontinalis


N
WOODHALL LOCH NX673675
53m
100m


CLONYARD LOCH NX 857554
34m
N
marsh
100m


WHITE LOCH NX 864547
32m
N
100m

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