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THE ROMANS AND STRATHCLYDE: THE ROAD SYSTEM
1. General Description of the Roads

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Renfrewshire Natural History Society

Introduction

In 1954 an ancient road was traced round the east shoulder of Burnhead Moor, above Greenock. By 1963 it had been established that this road connected with the Roman fortlet on Lurg Moor (Feachem 1953), that the fortlet was Antonine (Robertson 1966: 198-199), and that the road continued westward. In that year the authors joined forces and by 1970, with the discovery and excavation of the fortlet at Outerwards, had completed their initial project, i.e. the recovery of the road system servicing the western flank of the Antonine frontier (Newall 1976a: 111-112 and Fig. 1).

So began a series of road surveys still in process (Newall 1975: 79, 90). This present paper gives an overall account of the Roman road system in Strathclyde, as a general introduction to our researches (Newall and Lonie 1990a), based on a close study of maps and aerial photographs subsequently tested on the ground, and on the results of several personal traverses over the greater length of the entire road system, and records the results we had achieved by spring 1989 (see Figure 1). It is immediately followed by a second paper (Newall and Lonie 1990b), which examines in detail the roads of the western flank of the Antonine frontier (Route A), and subsequent papers in the series will then consider the remaining routes. All Figures will be numbered consecutively throughout the entire series of papers.

Antiquities proximate to the road in Renfrewshire have been separately recorded (Newall 1976b, 1977, 1978). Of these, the round houses have been referred largely to the Bronze Age following excavations at Martin Glen (Newall and Newall 1980). Excavations at the tribal capital of Walls Hill failed to establish any Roman connection (Newall 1960), and no great population has been determined for the Roman period. Other antiquities are described where relevant.

The Road Systems

ROUTE A. North Section. The western flank of the Antonine limes (i.e. frontier), comprising the main trunk road from Whitemoss

Fort via the fortlets on Lurg Moor and Outerwards towards Largs and beyond, and an advanced early warning patrol road servicing a signal station on Hillside Hill above Inverkip, sited to receive signals from the Firth of Clyde and perhaps Argyll. This system would appear to be of Antonine origin, nor does the lone bronze of Nero found close to the road at Gleddoch, Langbank (Robertson 1963: 148) question the attribution. The light population could well be contained in the first century by Route B and the south section of Route A.

ROUTE A. South Section. Possibly a link from the Avondale road (St. Joseph 1952), this road is probably reaching for a common terminus with the North Section at Hunterston and the harbour at Brigurd Point. In view of the several first century phases at Loudoun and the known activity of Agricola's fleet in the west, this road is probably of the first century.

ROUTE B. Section north of Loudoun. A road reaching for the fort on Barochan Hill and the ford on the Clyde.

ROUTE B. Section south of Loudoun. A road passing via Muirkirk, partly re-used as the Old Sanquhar Road, to join Route C in a T-junction.

ROUTE C. The main cross country link traced from the above T-junction, eastward to the Garf Water beyond which it probably continues as the known Biggar?-Carlops road towards Elginhaugh, and westward to near the Clyde coast some two miles north of Girvan. This is almost certainly heading for a permanent fort north of the recorded Girvan marching camps, from one of which came a fragment of first century A.D. Roman glass (Keppie 1986: 99). Over the last stretch Ailsa Craig is in full view ahead as a light coloured rock in an expanse of sea. It is difficult to avoid the conclusion that the destination is the fort of Vindogara, the White Rock (Rivet and Smith 1981: 501) named, as Newstead (Trimontium), from an outstanding local landmark.

ROUTE D. This is the road from the Clyde via Drumquhassle, Malling (Lake of Menteith) and Bochastle traced by us as far as the descent towards Dalginross. Reference to an early road on this line has been made. Richmond and McIntyre appeared initially to consider the possibility (Richmond and McIntyre 1936: 406), then to doubt the existence of a road (Richmond and McIntyre 1939: 111), and finally to reject it completely, as far as Fendoch was concerned (Ogilvie and Richmond 1970: 69).

ROUTE E. The Nith Road. The southern length may be referred to in charters of Melrose Abbey cited by J. Macdonald (Macdonald

1894: 43, 317). Traced from W.N.W. of Drumlanrig to opposite Sanquhar, this must surely cross the Nith in the vicinity of Crawick. Thereafter it would seem feasible that Route E south, Route B, and Route D are links in a continuous road. If so, then the short northern stretch of E which passes via Street, as foreseen by Clarke and Wilson although not tested by them (Clarke and Wilson 1960: 152-153), is not in line and may be a secondary link road towards the west coast.

ROUTE F. The probable continuation of the road east from Raeburnfoot via Craik Cross to the Borthwick Water. This route was first suggested as Roman by Hardie (1942), a suggestion examined critically by Richmond (1948) who commented that Hardie's studies had "all the strength that is to be derived from a detailed knowledge of maps and all the weakness of work unrelated to examination of the ground". In his own examination Richmond accepted Hardie's dating for the stretch from Mid Raeburn to the Borthwick Water, but not beyond on the ground. However he did accept that this was part of a cross route linking Newstead via Raeburnfoot and the Esk Valley to Netherby. His further consideration of the road via Eskdale towards Lockerbie was presented by Graham (1950).

ROUTE G. Short lengths of road east and west of Gatehouse of Fleet. The Corse of Slakes road has already been suggested as Roman based (Truckell 1960: 29) while a short stretch close to the fortlet has been examined and accepted as Roman (Keppie 1986: 89).

ROUTE H. An ancient road with Roman characteristics between the Calder Glen, Dalmellington, and Rankieston.

ROUTE J. A cross road linking the Newstead-Lyne road with Dere Street, and aiming to join the former midway between Lyne and Newstead at the precise appropriate position for a Roman site (Lonie 1988b).

ROUTE K. A road over Ettrick Head, the earliest of several. This, being a named route, is certainly ancient (Lonie 1988a). Moir (1975) describes routes in the area and refers to the Penera Cross Road.

ROUTE L. A road at Ardlamont, predating by several centuries a main turf land boundary dyke, and with Roman characteristics in its construction.

Topographical Disposition

Scotland is divided into distinct regional zones, and hence not improbably distinct tribal territories, by three main geological fault lines: namely the Great Glen, from Fort William to Inverness, the Highland Boundary Fault, from roughly Helensburgh to Stonehaven, and the Southern Uplands Boundary Fault, from Girvan to Dunbar. These parallel features impose their framework upon the Roman road system, which was essentially in the main laid down by Agricola, for in seeking to control the several tribal groups by drawing a ring of forts and roads round them, he was obliged to close their natural frontiers, as, for example, by the so-called 'glen blocking' forts along our Route D. Along this, the Highland Boundary Fault line, for Helensburgh to Stonehaven read Drumquhassle to Stracathro. Similarly our Route C and the continuation towards Elginhaugh closely follows the Southern Uplands Boundary Fault, and for Girvan to Dunbar we may read Girvan to Elginhaugh.

Not included in our map is the road linking Learchild with High Rochester. Did this continue south-west via an unknown fort on the North Tyne and via Broomholm to Birrens? Did it link a series of 'glen blocking' forts along the northern limit of Brigantia? Was it Agricola's final act before striking north? Whatever the truth, it will be seen that these lines and other intermediate lengths of road, such as the Avondale and Craik Cross stretches, all obey the parallelism forced upon them.

The main invasion routes ran roughly at right angles to the transverse routes, penetrating the hill masses through glens and river valleys. Thus we have lines of advance running roughly south-east to north-west, and cross routes from north-east to south-west, a fact noted by Keppie (1986: 42-43).

Much remains to be surveyed. The survey of the Avondale road to the coast is far from complete, as is our Route B north of Loudoun - in each case intensively cultivated ground is prohibitive of research. A coastal road between Girvan and Hunterston would seem necessary to link possible harbours. Irvine has often been suggested. The link between Gatehouse of Fleet and the Nith demands delineation, as does an essential link with Girvan via Minigaff. A road upstream from Glenlochar would further intersect the Galloway hills.

Granted all these roads, the two-directional system already outlined would be maintained.

Mapping

For a general map of all the known roads in the area of this survey, see Figure 1.

Having already walked the Roman road between the upper Clyde and Girvan, we are confident that without compass or map, maintaining only our point to point references, we can retrace our steps from the Clyde opposite Lamington to the coast north of Girvan. Over this fifty-odd mile length we could spend a comfortable four days, setting off with the sun at our backs and each evening following the sun into the west. With this fickle northern sun we travel west, not south-west, for without compass or exact knowledge of its declination we can be no more specific. Likewise, on the south to north routes, by night we might be able to judge our direction at any given point to within some ten to fifteen degrees of north, but with the necessary changes of direction of our road according to local topography we would be satisfied that we were travelling north. Given the general direction, a mileage and an assured destination exact bearing is not essential.

So with Agricola. He was driving north for the Forth-Clyde isthmus, for his fleet reconnaissance would already have established the far inland penetration of these two rivers. It is doubtful that his campaign notes involved mapping. At best we may assume south-north itera intervals between sites. Further as the imposed topographical parallelism ensures a reasonable equidistance between the cross routes, these may well have been recorded as east-west, again with site interval distances noted. Without close triangulation, not available to Agricola, and close astronomic observations improbable during a series of fast campaigns, no finer observations need have been recorded; nor are any directions given by Tacitus. Presuming this to be the case, in an attempt to see the northern campaigns through Agricola's eyes we have turned our north-east to south-west routes to an average east-west direction.

The result is thought provoking; the map has assumed a distinct Ptolemaic slant. If we turn the Clyde-Carlops-Elginhaugh road to east-west we have turned through about 55 degrees. Likewise, to turn the line of 'glen blocking' forts to east-west we bracket about 47 to 50 degrees. These are averages, but it may be that they account for the approximate one seventh of a revolution turn of Ptolemy suggested by Rivet and Smith (1981: 114). The Marinus-Ptolemy information on Scotland depended on the field notes of Agricola's campaigns. The speed of these, coupled with the short tenure of Scotland and the time taken for the information to reach Marinus, would not allow of finer observation. In view of the imposed topography, no more accurate statement than south to north or east to west need have been given. Doubtless

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Figure 1

General Map of the Roman Roads in South-West Scotland

Roman roads lettered Routes A to L

Roman sites numbered 1 to 39, as undernoted:

1. Outerwards
2. Hillside Hill
3. Lurg Moor
4. Whitemoss(Bishopton)
5. Barochan Hill
6. Drumquhassle
7. Malling
8. Bochastle
9. Dalginross
10. Fendoch
11. Inchtuthil
12. Ardoch
13. Strageath
14. Bertha
15. Cargill
16. Cardean
17. Loudoun
18. Bothwellhaugh
19. Camelon
20. Girvan
21. Castledykes
22. Castle Greg
23. Cramond
24. Crawick
25. Elginhaugh
26. Inveresk
27. Drumlanrig
28. Lyne
29. Gatehouse of Fleet
30. Glenlochar
31. Dalswinton
32. Murder Loch
33. Milton
34. Oakwood
35. Raeburnfoot
36. Newstead
37. Doune
38. Mollins
39. Birrens

distances between forts were reasonably accurate, but the coastline would be an envelope based on seamen's calculations loosely co-ordinated by land measurement, and more accurate only where the Roman army had fixed sites. Hence, in a limited survey by a fleet returning to base at the close of a campaign, it is doubtful if any accurate measurements were made between Duncansby Head and Cape Wrath. On this misaligned framework Ptolemy made his final adjustments.

One additional identification may be possible. The local pronunciation of Crinan as Creeonan may preserve the stem of the name Creones.

If there is any significance in the above, then any sites calculated from Ptolemy on an east-west basis ought to be reorientated to the north-east to south-west inclination. This would result in the Vindogara-Irvine equation of Rivet and Smith changing close to a Vindogara-Girvan equation (Rivet and Smith 1981: 124 and Fig. 7). However, our purpose was not to consider Ptolemy but to view Scotland as Agricola may have seen it; nor is the viewpoint uninstructive.

Here we see the ability of Central Command to switch forces at Newstead, taking either the Lyne-Castledykes route in a push towards the ford on the Clyde, or the Elginhaugh-Camelon? route - which clearly requires close survey - doubtless towards the lowest crossing point on the Forth. Likewise, from Birrens a force could travel via Dalswinton and Loudoun to the Clyde or switch to reach the central or the east route. The 'missing' road directly south from Castledykes need not exist, but a link between the Annan valley road and the Lyne road should lie close to Castledykes.

The challenge of the west is emphasised in the outthrust Solway coast, but that this flank was covered by thrusts into the west is suggested by the several phases of Flavian occupation detected at Dalswinton and at Loudoun, connected with Castledykes (Steer *et al.* 1978: No. 262). Here Agricola would require the time he allowed himself for consolidation after he had secured the Forth-Clyde isthmus.

Finally we notice the unimportant lightly populated little salient of Renfrewshire, controlled from Barochan, which faces west, and possibly also from a fort intermediate to Barochan and Loudoun just south of Neilston (Newall 1975: 83), and sealed on the south by Route A south.

Route D and the Forth-Clyde Interval

We have now, with Agricola, reached the Forth-Clyde isthmus. On the west, before us on the Clyde is the Dumbuck ford, and on the east flank the Forth continues to curve 'north'. Behind us the Southern Uplands are penetrated by our supply roads, and are effectively sealed on the south by a line of forts from Birrens to Learchild, with outflankers on the west, and on the north by our Girvan-Elginhaugh patrol route. This with outliers at Loudoun, itself to be linked with roads, and possibly at Castle Greg, also effectively seals off the people of the Central Lowlands. It is essential that their northern bounds be secured. In all logic it is inconceivable that a halt be made on the Clyde. Equally it is impossible to stop until the Forth is made secure.

The multi-pronged advance is reflected in the small size of such camps as lie along the route to the isthmus. These continue along the Highland Boundary Fault line as far as Dalginross, and the common Stracathro gateways suggest strongly that they are the work of one legion. Of significance is the presence at Malling of two camps of this type, the smaller possibly a construction camp (Hanson 1987: 125).

We are told by Tacitus that when Agricola's forward troops had reached the Tay there was time left to build forts. It is not impossible that Malling reflects the forward movement, and the presence of a vexillation left to construct the fort at the close of the campaign. A cross route may link Bochastle with the east road via Doune, which covers a main fording point, but with a *limes* covering the Highland line boyond which lay people of a different ethnic origin from those now enclosed, the focal point for roads coming from the east along the Forth and from the west across the Clyde should be where the *limes* nearest approaches the sea or its reach on the Tay, i.e. somewhere close to Inchtuthil, possibly Cargill (Fort 2). The sudden swing along the Gask ridge is contrary to the forward move and ought to relate to the close of the campaign, possibly because the Highland line had already been secured.

The final events of 79 (or 80) A.D. are related by Tacitus in a typical terse summary statement, "-*inventus in ipsa Britannia terminus namque Clota et Bodotria, diversi maris aestibus per immensum revectae angusto terrarum spatio dirimuntur quod tum praesidiis firmabatur, atque omnis propior sinus tenebatur summotis velut in aliam insulam hostibus*".

All *limites* up to this point were inevitably "*in Britannia*". "*Ipsa*" emphasises that this was the limit of *limites* just within the bounds of Britannia south of Caledonia (Ogilvie and Richmond 1970: 233). We submit that only the 'glen blocking' line can satisfy this sense.

"*Omnis proprior sinus tenebatur*". Granted that this could refer to the curve of land enclosed by the Highland line, it could also properly refer to the entire curve of the Forth, and its extension by the inner line of forts and watch towers along the nearer side of the "other island", terminating on Bertha with Cargill (Fort 2) covering the flank. It need not refer to land south of the "*terminus*" being discussed, for Agricola clearly had much consolidation yet to organise in that direction.

Since the enemy had been pushed back (or aside) as if into a separate island - "*summotis velut in aliam insulam hostibus*" - Tacitus might here with hindsight refer to Caledonia, for the proof that Britain was an island lay in the future. To refer to the entire Highland mass as an island, however, is truly rhetorical. If in fact Fife were the other island, then the swinging of the eastern route along the Gask Ridge could indicate the herding of the enemy, and the subsequent line of watch towers would complete the sense of "*velut in aliam insulam*".

The large camps at Dunning and Abernethy cannot refer to the close of the campaign. Their role is in the future when the army has been regrouped. Since they imply an investment in force we need not maintain that the Venicones were philo-Roman, hence we cannot treat Fife as a protectorate with the Gask line a late erection for its defence. With the Highland line in existence this would not be required; with it abandoned at a time of withdrawal, to hold the Gask line would be to invite a war on two fronts, in view of the northern enemy. It seems feasible to accept the Gask line as a cordon to keep watch on "the island" until the next move forward. It is significant that this was to engulf the tribes beyond the Forth. Thereafter the watch towers might be dismantled. The main fear was of "*motus universarum ultra gentium*". But before that move the south had to be made safe. This demanded a secure frontier, which could be provided by the 'glen blocking' forts serviced as a *limes* by our Route D, and by the eastern route fortified along its line from Camelon. These must have been completed at the close of the advance on the Tay.

Indications of Road Antiquity

It has been generally assumed that between the Roman occupation and General Wade there were no made roads. This is improbable, given the ability and the work force at the command of the great ecclesiastical houses. Their early charters indicate the main roads, as does that of the Royal Burgh of Ayr. Nor is it unlikely that the barons improved communications within their bounds. Macdonald (1894: 43), quotes a charter of

1250 granted by Sir John Comyn to the monks of the Abbey of the Convent of Melrose granting them passage through his lands of Dalswinton. He continues "if the aforesaid road through inundations, or its being long used for wagons get out of repair, the monks and their dependants shall have full liberty to renew the same road by ditches and causeways or in any other way they please".

Such a road, if abandoned early, will over the years accumulate a considerable overburden, and while it is axiomatic that a road fallen out of use in the 17th century can scarcely support a humus of above two to three inches, over mosses and peat moorland, where later tracks tend to follow earlier hardways, the antiquity of a road may indeed be doubtful, especially where the overgrowth has been reduced by traffic.

Indications of age are readily listed. The road should have a considerable overburden. It should point the way for later tracks - hence the antiquity normally granted to 'drove roads'. It should be a known named road - such as the Minchmoor road, or the Wheel Causeway, etc. It should be followed by early boundaries - parish or mediaeval land divides. And obviously it should also be recorded in early documents. To the above we would add that it might have associated with it place names including Hole, from the Welsh *heol* = road or track, and possibly Sorn if equivalent to *sarn* = causeway. Numerous instances of Hole, Holehouse, etc. can be cited along the known Roman roads, and we will instance several on ours. However, since the Britons of Strathclyde survived into the early mediaeval period the use of *heol* is not of itself indicative of more than mediaeval or earlier. Holehouse on the ancient Kilbirnie-Fairlie cross track does not indicate a Roman road nor the Luggie Hole, the old lane which reaches the shore near the east Langbank crannog. Further, hole may derive from natural features, caves, hollows, etc., or from animals. The ultimate indication is major erosion of the entire road.

The greater lengths of the roads to be described pass over peat moorland, and it can be stated that in general, except in the deeper mosses, the overburden is of some eight or nine inches (0.23m) of peat, and where the road is laid over peat, of approximately equal thickness to the peat bedding beneath the roads. In all our surveys, we have established that at every point our road is the earliest. All Roman roads by their very nature attract later tracks, hollow ways, etc. A pioneering through road will attract a veritable skein of other roads, such as Route D, where in Glen Artney some five to six major roads, some with side issues, have to be unravelled. The Gatehouse of Fleet road is similar, but with fewer main roads to consider. Or the road may be arterial and attract side roads, farm tracks, etc. Such is the Auld Clay Road (A south), where in the initial study of maps and aerial photographs we were surprised by a very network of roads converging on an artery which was not always visible.

At times our roads were followed by drove 'roads'. We can state categorically that there is no such thing. There are droving 'routes'. These broad grazing swathes follow known through routes, and many a Roman road has suffered. Over cultivated or grazed ground they have been enclosed by banks and fences, hence the suggestion of 'road'. Drovers had neither the time nor the ability to make long through roads. Occasionally, however, drove routes do indicate existing roads.

While there are therefore numerous indicators of antiquity, there are only two true indices of a Roman road.

a) That it should run between known Roman sites. Such are our Routes A, B, D and most probably C and E.

b) That it should conform to acceptable Roman construction, i.e. that it should have a specific anatomy.

The Anatomy of Roman Road Construction

a) Structure. The Roman road is normally laid on a prepared road bed, usually terraced, and from which the top soil has been removed. A substratum of heavier cobbles is laid down, and on this is beaten a cambered mound of small metal in earth or clay, or of gravel. Over the peat moors, however, such a road would tend to sink and for many miles our roads, as exposed in numerous moor or forestry drains, consist of a layer of hammered clay, stiffened wih small metal, at times of almost cement-like hardness, and lightly surfaced only with small metal. Cushioned on peat, without heavy substratum, this would act as a resilient plastic ribbon yielding to pressure and resuming its position when relieved. (The first author well remembers his surprise at observing on Islay the long straight road between Port Ellen and Bowmore acting in this fashion. Now tar-macadamed, the road then sank visibly for several inches beneath the weight of a distillery supply tanker, only to rise rapidly behind the vehicle because of the peat beneath). This structure is present on Routes A north, B, C, D and E. On downslopes, however, especially on the descents to streams, the cobbled substratum is always present, possibly to prevent slip, and there is more stone in content. Here the peat is generally thinner or is not present.

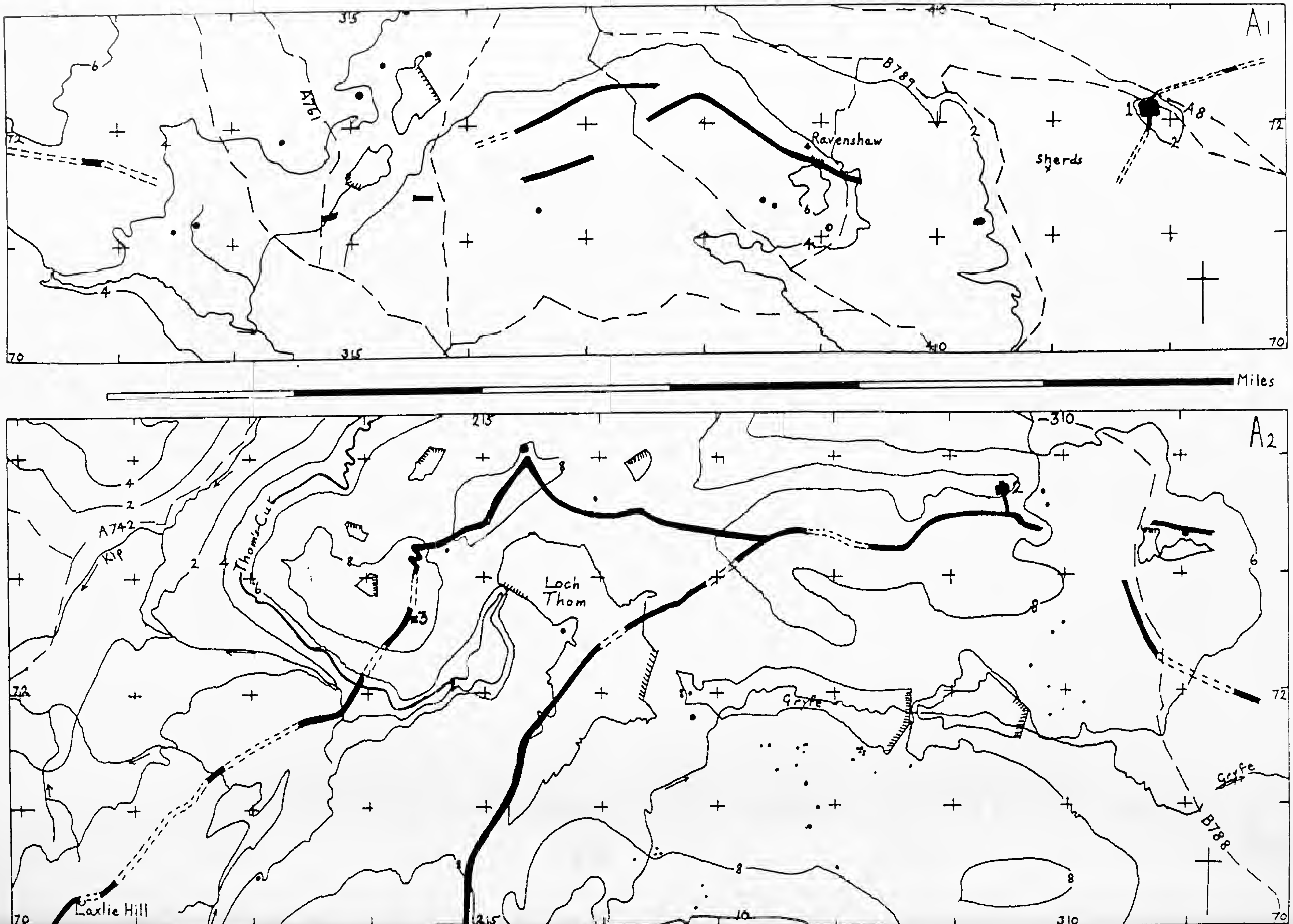
b) Terrace. The road is normally terraced, for it seldom crosses dead level ground, but even there the road bed is prepared. The terrace is normally much wider than the road, for in its cutting is obtained the material for the road proper. We should perhaps envisage the unwanted top soil being pushed to one side, and the earth and stones from which the actual road is to be made, pushed to the other. A normal width is some 10 to 11 metres. Even over peat moorland the terrace may be detected, and while the road is now the plastic ribbon on peat, the levelled bed may be seen occasionally bearing an underlay of different coloured peat, or twigs and branches (Routes A and D). The source of the clay for these roads has not been satisfactorily determined. It may have come from nearby exposures in river banks, etc., although on occasion small sinks like peat cuttings have been noted close to the road (Route A). Where the peat is of no great depth it has been removed in places to provide a sunk passage (Routes B south, E south, and especially D).

c) Level Ground. Over hard ground the clay road normally reverts to the small metal on cobbles, but such is individual persistence that over a hard rise at Drummond's Knowe (Route C east) between stretches of peat moorland, despite the fact that the entire knowe is surfaced with eroded whin chippings, the cambered red clay mound with little metalling continues unaltered. However, over extremely hard ground, on rock, or with but a thin cover over rock, a thin layer of compacted rock splinters only a few inches thick has sufficed (Route A) and on the approach to Lurg Moor fortlet at one point ruts on the bare rock suggest that this thin layer was readily worn through.

d) Extreme Side Slopes. On side slopes in excess of 30 degrees gradient the normal terrace is cut to only half width, and is buttressed along the downslope edge by a built mound to provide the normal road bed width (Routes A and D). But on occasion (Route E south, Route K and on the Durisdeer road) a stepped terrace is provided to allow for a road at least on the upper shelf. The impression is of a dual carriageway.

e) Downhill Stretches. It is clear that the Romans abhorred a direct downhill road, as indeed do the later investigators. To the Romans it meant much more work in providing bedding to prevent slip. To us it presents a very widely spread mound dissected by erosion, reduced and spread by ice, rain water and soil creep, possibly mutilated by the overflow from choked abandoned side ditches, and presenting at best a broad blaze of rough vegetation (Routes A, Loch Thom N.E., Route C east).

f) Quarry Pits. The shallow, small round borrow pits, so plentiful alongside the upper Clyde road north of Moffat and on stretches of Dere Street, are referred to as indicative of road construction, but these lie beside through roads which have



A1
Ravenshaw
Sherds
B789
A8
A761
Miles
A2
Loch Thom
Thom's Cut
Gryfe
B788
A742
Kip
Laxlie Hill

Figure 2

Route A. North Section

Map A1

Alternative roads west of Whitemoss Roman Fort (1)

Map A2

The patrol road leaving the trunk road west of Lurg Moor
Roman fortlet (2) to service the signal post (3)
on Hillside Hill

probably seen use throughout the history of Roman Scotland. Although we have encountered many examples over the entire length of our roads, these were relatively few compared to the very large numbers which have been found beside Roman roads elsewhere in Scotland. Of primary function are probably a few close to river crossings where extra metal was required. On the east bank of the Doon (Route C west) a very large pit clearly provided the material for the long diagonal descent to the river. However in general we consider that terracing provided sufficient road material. On Route A, at Outerwards quarry pits are actually dug into a disused loop road, and to the south follow a length of road which had been provided with a central strip of metal. Here the quarry pits are secondary and relate to repair work. The many intersecting pits north of Moffat suggest repair work on more than one occasion, while on Dere Street, the almost regimentally laid out line north of Brownhart Low, along a stretch where the road has again sunk, suggests major organised resurfacing of a weaker stretch of road.

g) Cutting and Embanking. Where the road has to clear a steep ascent a continuously smooth gradient is achieved by cutting into the face of the hill or scarp and spreading the spoil beneath the cutting in a ramp extending from it. Near Lurg Moor fortlet two volcanic scarps are taken in a series of two cuttings and two ramps. The extreme long ramped embankment rising to a broad cutting may be seen east of Gatehouse of Fleet, and a re-entrant cutting reached by a curving bank rises to Hillside Hill (Routes C and A). A major ramp may be seen west of Goldenberry Hill (Route A south).

h) Expansions. On the patrol road (Route A) east of Scroggy Bank the track twice expands to double its width for a short distance. These are surface indications. However, south of Outerwards, exposed in drains there was recorded an additional eight foot (2.44m) width of clay and cobble road, running for at least thirty feet (9.15m) along the west side of the road (Figure 4, Section b). The Monadh Odhar example (Figure 4, Section c) where the addition, of unknown length, lies on the upper edge of the road bed, alongside the upper scarp, indicates that this is of a build with the road and is not secondary. A third example occurs near the March Burn (Routes A, D, and C west). These are independent lengths of narrow road, and are not analogous to the side expansions or hard shoulders as reported at Ardoch (Breeze 1973: 122-124). We remark that they occur at the top of long climbs. It may be that horses were rested or changed. Margary (1973) records few instances, not necessarily on sloping ground as on Peddar's Way - "a causeway 16 feet wide .... with an extension 4 feet wide on the east side, apparently a path" (Margary 1973: 259). On the Chelmsford-Colchester road is recorded a triple causeway with a central road 27 feet wide and side roads c. 15 feet across (Margary 1973: 248).

River Crossings

Over the uplands the roads are terraced above the main streams to allow the tributaries to be crossed normally below the junctions of the headwaters, often just above a gorge. The minor streams are frequently culverted, when the stream bed has been excavated to a depth of up to one metre and lined with boulders to leave a passage one to two feet (0.30-0.61m) wide. Usually the road is ramped over these on cobbled planes. Thus at most streams a heavy accumulation of stones is present. Often the culverts are gone but a tongue projects where the stream has been diverted, and on the opposite bank is a stony face or truncated mound where the approach has been eroded. In several cases weirs or constructed falls have been detected a short distance upstream (Route A, B, C, E south and probably D). These would create backlash in turbulent conditions and ease the flow against the culvert face or over a ford. Instances will be presented where an apparent extension or rebuild of a fording place deduced from additional 'kerbing' upstream may in fact indicate a low weir, and it is possible on larger streams that disturbed lines of boulders may be the vestiges of larger weirs.

At times the descent to the deeper valley bottoms is dramatic, the road plunging diagonally down the bank, normally, but not always, in the final approach to the stream inclining upstream. On such descents, if wagons were being used, brake horses descending backwards may have been employed. On the more abrupt banks the eroded stumps of bridge piers survive. In all cases wooden bridges were almost certainly constructed.

At major crossings, as on the Clyde at Dumbuck and at the Verge (Steer *et al.* 1978: No. 262), possibly on the Eas Gobhair south of Bochastle and the Garb Uisge to the north, use has been made of a mid stream island. This would allow a channel to be diverted during the construction of a ford. At the Verge the river bottom is tightly cobbled.

Drainage

Only in a few cases can we cite instances of indubitably primary side ditches, despite the numerous sections available, and few culverts have been recorded. Over moorland the underlying peat will have ensured seepage beneath the road, inevitably assisted by culverts, but over long stretches

(Routes A and D) the road is taken along the break of slope edging a peat plateau, ensuring a steady bleeding of the moorland beneath and downslope of the road. On such a stretch on Route A a sequence of rivulets flowing over the road from the dammed-back moss may have originated in blocked culverts, while on a similar short stretch above the March burn (Route C west) their presence is betrayed by swallow holes.

Side ditches persist along the Corra road, Ardlamont (Route L) and here alone have we an example of a major scoop ditch from which road material was dug (Margary 1973: 19), although the readily detectable side drains are due to secondary use over wet moorland. Significantly they cease on either side of a travelling turf land boundary dyke, beneath which the ditches had almost completely silted up and several inches of humus formed over the road.

Signalling

The roads are so aligned from point to point, or ridge to ridge in broken country, that signalling could be readily achieved by out scouts operating in advance of a column on the march. The apparently inexplicable loop north of Scroggy Bank on Route A ensured signalling to Lurg Moor fortlet, while the main trunk road to the south is in full view from Corlick Hill which could be manned from the fortlet, and from Hillside Hill, and covered between Lurg Moor and Outerwards by Berry Hill. Other routes are similarly covered and there is no need of built signal stations where scouting can be operated from a fort. In different case is the high placed signal station on Hillside Hill (Route A patrol), clearly placed there with a specific function. It covers the western approaches to the Clyde and could receive signals from the fleet, or even, granted a Roman origin to Route L, from Argyll.

Similarly high placed stations should be long distance pick-up points establishing contact between routes or systems, as possibly Eildon North and Fendoch. From Callander Crag above Bochastle, Stirling is in full view, and while the Crag could be manned from the fort, a signal post as yet unlocated may lie in the vicinity.

Finally our Route A south mounts Goldenberry Hill in a steep 1 in 5 rise with the clear intention of commanding the height. From it the entire Firth of Clyde is covered, including Hillside Hill, the road from Largs to Outerwards, and the heights above Ardlamont. On the hill is an enclosure suggestive of a fortlet (Newall 1966: 16). However, a trench taken across the centre of the west side in 1970, with the interested permission of Mr William Adams of Auchenames, Portencross, failed to date the site. A 'ditch' proved to be a natural syncline in rock. The rampart of black earth fronted by large blocks was not distinctively Roman, nor was any artefact recovered from the interior. Nevertheless the site could be manned as an observation post in emergency, if not habitually, possibly from the harbour of Brigurd Point towards which the road is directed (Newall 1976a: 122).

Road Widths

Margary (1973: 21) states that "on important roads 30 feet seems to have been about the maximum, 24 feet or so being very often found, and in lesser roads a width of 15-18 feet is very common indeed, but they were sometimes as narrow as 10-12 feet". With this we largely concur, although we have few instances of the minimum bracket other than in fort gateways. The measurements are approximate, the road being above or below the stated whole number of feet in width, nor is the precise measurement maintained throughout any given length. Over our key measurements, 10 feet (at forts), 16 feet, 18 feet, 21 feet, 24 feet and 30 feet, allowing for imprecision we have the Roman equivalents 9.7-10.7 feet = 10-11 *pedes*: 15.5-16.5 feet = 15-16 *pedes*: 17.5-18.4 feet = 18-19 *pedes*: 20.4-21.3 feet = 21-22 *pedes*: 23.3-24.3 feet = 24-25 *pedes*, and 30.1 feet = 31 *pedes*. While the very common measurement of c. 24 feet can be 10 *gradus* (5 *passus*) = 24.25 feet, for other measurements the *pes* provides a more flexible cover.

Appendix: Notes on the Native Tribes

It has been asserted by several scholars that while the Votadini, and even the Venicones, were amenable to the Roman way of life, the Selgovae were hostile. A biased viewpoint is induced by the numerous Roman finds from the extensive excavations at Traprain Law. Yet Trapain is but one site, and if we consider the distribution of finds of Roman origin from native sites (Robertson 1970) it is difficult to maintain that one tribal region is more productive than another, nor is Fife especially favoured. Aspects of the Roman control of Scotland in forts and roads have been adduced; yet we see that the main advance was by natural corridors of penetration, along which the established supply roads were necessarily fortified and lined with changing posts. The Votadini are covered by the Newstead-Elginhaugh-Camelon line, along which further posts will be found, and by the Clyde-Elginhaugh cross route. Newstead, a key fort in the system and also a 'glen blocking' fort, could scarcely have been sited elsewhere. Its importance was such that no major native site could be tolerated in the vicinity, no matter the tribe.

Certainly the Romans do not appear to have reduced the power of the hostile Selgovae, who persisted in the Ravenna Cosmography and during the struggles for nationhood in the 6th and 7th centuries were allied with the Britons of Strathclyde (Damnonii) against the Saxoni (Irving 1865: 192). It occurred to the first author that if the Genunian affair as recorded by Pausanius did in fact refer to Britain, then we had a clear statement that one tribe north of Hadrian's Wall was probably of client status.

It further appeared possible that the section of the Brigantes now excluded from the province by the wall would have been made safe, possibly also by being granted their lands as clients subject to Roman conditions. Thus their lands could be resumed by the Romans if the tribe proved troublesome, and after they attacked the district of the Genunae, they did indeed lose their lands.

Following a discussion with the first author, Professor Robertson later attributed to him the suggestion that the Novantae were involved (Robertson 1975: 284). The time therefore now seems opportune to present the full argument, that the tribe involved was in fact the Selgovae.

The problem was to arrive at a name from which Pausanius formed the adjective Genounian. No Genunae or Genonae are recorded in Britain, but the neighbours of the Brigantes were known. Of these, two had trisyllabic names, the Novantae and the Selgovae, and of these not only were the Selgovae the nearer but the name presents the same sequence of vowels as Genonae. It seemed possible that a hastily scribbled cursive S could be misread as G (= Gelgovae). Further consideration of script suggested that a ligatured cursive lambda-g with faint initial upstroke might be misread as v (= Gevovae). Thereafter, a scribe who did not know the origin of the recorded tribal name could have taken it for Greek and written Genonae. This hypothesis was proffered as highly speculative, as indeed it remains.

Since then Rivet and Smith's *Place Names of Roman Britain* (1981) has been published. For the Latin S to G error we find no parallel, and Segantiorum for Gesantiorum (Rivet and Smith 1981: 457) looks like simple metathesis, but for the postulated lg to v change see Delgovicia and Devovicia (Rivet and Smith 1981: 331). Numerous analogies for the o-u (ou) transfer and for the n-v equation may be cited. If this identification is sound then the Selgovae have indeed been miscalled.

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THE ROMANS AND STRATHCLYDE: THE ROAD SYSTEM
2. THE WESTERN FLANK OF THE ANTONINE FRONTIER

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Renfrewshire Natural History Society

Introduction

The first paper in this series (Newall and Lonie 1990a) gave a general description of all the known Roman roads throughout the area. This second paper (Newall and Lonie 1990b) deals in detail with Route system A, the western flank of the Antonine *limes*. The Figures illustrating the series of papers are numbered consecutively throughout.

On the general map (Figure 1) land over 750 feet is stippled. On the strip maps (Figures 2-4) contours are shown in hundreds, e.g. 3=300 feet. The Roman road, where proved to be continuous by visual remains, seasonal vegetative change, or by drain section, is shown as a continuous thick black line. Modern roads are shown by a broken thin line and the relevant highway number. Other mapped details are selected as they best illustrate the text. The factual reports are from the results, jointly agreed, of field surveys where the greater length of the roads has been traversed at least twice.

Sir George Macdonald, discussing Bede's statement that the Antonine Wall ended "near the city of Alcluith", and the assumption that the limes extended to Dunglas to control the then existing ford, suggested that "a small castellum on the southern shore would have been both cheaper and more effectual" (Macdonald 1911: 109-110). When it was shown that a road had run westward from the fort at Old Kilpatrick (Millar 1928: 7-8), Sir George preferred the possibility of a Roman harbour at Dumbarton (Macdonald 1934: 186-187). His initial logic was later vindicated by the discovery of a castellum on Whitemoss Farm, Bishopton, NS 418721 (Steer 1951), but the unsubstantiated harbour on the 'enemy' side of the river at Dumbarton still finds acceptance.

From the Antonine fort at Whitemoss, an equitate quingenary cohort could patrol the Leven Gap, contact Old Kilpatrick, and outpost turmae (cavalry squadrons) to the fortlets on Lurg Moor and Outerwards ridge. From the north gateway a road resurfaced at least once turned north-east towards the Clyde ford. It is now known that this was reached by a road of first century A.D. construction (Route D), but in 1963 this discovery lay in the future.

In 1974, when ground was being graded for the M8 motorway, the scarping of a brae face exposed a section 104 yards (95.7m) east of the stream flowing north from Slateford Lodge, and just north of the railway wall, at NS 425724. Heavy kerbs edged some 10 inches (0.25m) of small cobbles, 50 feet 6 inches wide in oblique section, between small ditches 3 feet (0.9m) wide by 2 feet (0.6m) deep. Over these, and petering out beyond, was a spread of small cobbles in gravel, slightly cambered. Above, compact gravel surfaced by lighter gravel rose to the humus. A reduction of the oblique section to c. 18 feet (5.5m) swings the road towards Whitemoss fort, north gate. No road issued from the west gate, which is confronted by a steep scarp, and the east gate lies under the modern road, but from the south gate traces of a road ran south, to be paralleled by the track to Whitemoss Farm. A hollowed descent near the north east corner of Castlehill, NS 41007145, has near recent surfacing, but from the field a short distance to the west, NS 40957156, were recovered a sherd of amphorae and a sherd of ribbed white pipkin.

ROUTE A. NORTH SECTION

Beyond Castlehill the first trace of Roman road emerges from a plantation north of the 'bloody pond', a terraced track which, west of the Barscube-Langbank road, NS 39137159, continues as a raised metal road 18-21 feet (5.5-6.4m) wide towards the north terrace of Barscube Hill. The length of road over Barscube Hill west of Whitemoss was indicated by, and partly traversed with, the late Mr. James Fraser of Bellevue, Kilmacolm. He stated that, in his boyhood to an older generation in Langbank, this was known as the Roman road. Secondary metalling fades off towards Ravenshaw farm to leave a familiar rounded profile, until south of Ravenshaw the brae face is mounted obliquely, by parallel cutting and embanking to form a partly terraced, partly buttressed ramp, NS 39037167, as at the March burn (Route C west) and the approach to the Allt an Dubh Choirean (Route D). See Margary (1973: 121) for a similar build, but only 10 feet wide on a steep spur.

Ahead there is a track, green through rush and heather alike, and 21-24 feet (6.4-7.3m) wide on a 40-50 feet (12.2-15.2m) wide terrace, which fades over lower ground where, as grading for Gleddoch golf course revealed, a whin-chip metalled strip some 4-5 inches (0.08-0.13m) thick and 18 feet (5.5m) wide surfaces the subsoil.

South of the deflection of the Gleddoch plantation boundary wall the familiar agger rises, 25 feet (7.6m) wide centering a 50 feet (15.2m) wide strip, and so runs, NS 38507192 to NS 37937221, towards Undercraig Farm boundary fence where it curves from W.N.W. to W.S.W. to avoid marshland at NS 37957222. From Gleddoch a bronze of Nero was recovered (Robertson 1963: 148).

On Undercraig a faint ridge crosses a field to pass just to the north of the gate in the south-east corner, NS 37577206, into ground used as a gun-site during the last war. Signalling must have occurred in the vicinity as the Undercraig ridge masks Whitemoss from Lurg Moor. Between the former gun-site, Padanaram, and Lurg Moor there are considerable gaps and alternative routes present themselves (Figure 2).

The South Road

From the west side of Cairn Hill a terraced, partly ramped track descends to coincide with a faint road passing shallow quarry pits and quarried rock faces, NS 37207181, on its course towards Knockmountain Farm. A right of way from Kilmacolm to Langbank deflects to follow it for a short distance, NS 37107172. West of the wall which crosses it here, it gradually passes from south to north of a wall roughly aligned east-west, and descends a rock face by a graded metalled ramp to pass beneath a field wall, NS 36807164.

In ploughed land it continues, a broad stony ridge, towards the north side of Knockmountain. To the west the line is probably closely that of the existing farm road to Gallahill road, NS 35827136, and of the broad strip beyond, ditched on either side, which forms the parish boundary, to NS 35627140, and continues beyond for some distance downhill.

To the west only short stretches of road have been found, as follows:

(a) On the height north of Mathernock a road mound runs from just north of a small pond, NS 32857175, for some 200 yards (183m) towards Little Auchentiber Farm.

(b) From a present footbridge over a streamlet, NS 31667190, a flat track at least 18 feet (5.6m) wide travels for some 250 yards (228.6m) towards the north side of Little Auchentiber farmhouse to NS 31507198. Lengths (a) and (b) align, and then align with the projected continuation of the road over Burnhead Moor (see below). Baylie (1858) charts a track running from Burnhead Moor road end to Little Auchentiber but not beyond.

The North Road

From marshland, NS 37627233, a track is traceable westward past the north side of Gallahill Wood where it assumes the proportions of a major road mound and curves, NS 37057230, to W.S.W. to cross a spur west of the road on a 24 feet (7.3m) wide terrace. At a stream crossing, NS 36757213, secondary metalling is culverted, leaving the primary road edge some 6 feet (1.8m) to the north. The course is then direct to the south-west corner of Knockmountain Wood, NS 36207190, following the embanked boundary as a broad cambered track, but traceable with less certainty towards the bend in Gallahill road, NS 35727178. No connection with the southern route could be established. Of the two, the southern road is more probably Roman based, for the following reasons. It aligns with the Barscube road at Padanaram, it has two examples of ramped approaches to reduce gradient, it has several small quarry pits beside it, it imposes a kink on a right of way which thus acknowledges its priority, and finally, for a short distance it forms the parish boundary.

There are several sections, named and described as follows:

Burnhead to Lurg Moor:

Alternative routes can also be described on the approach to Lurg Moor.

(a) North-west of Little Auchentiber, beside the field gate west of the B788, the road is a cambered mound 24 feet (7.3m) wide accompanied by a hollow way and circular quarry pits, NS 30807231 to NS 30527290. Beyond NS 30657260 it sinks in marsh, and towards a fording point on the Devol Burn, NS 30457312, a hard track only is traceable. Wheel ruts show on bare rock. Beyond the burn no trace has been located directed towards Lurg Moor fortlet.

(b) North of the Harelaw Dam, from the field dyke, NS 31307329, westward to NS 30907342, a turf mound 21 feet 4 inches (6.5m) wide has been traced. To the east is cultivated ground, and as yet no clear traces have been defined to the west. A hollow way follows the north side for some distance then passes to the south. In part it reduces the width of the road mound. Later, tracks to the north run parallel to the complex with small quarry pits between.

Lurg Moor:

On Lurg Moor the first recognisable road length heads for the fortlet from the south-east, NS 29757337, where two closely spaced scarps are taken in one graded descent involving alternate cutting and embanking. Several quarry pits lie to the west on the middle terrace.

Below the lower scarp the mound, 24 feet (7.3m) wide, switches to due west to ford the Lady Burn. Between this and a T-junction to the west, NS 29557350, the extremely fugitive track bordering the north edge of marshland was betrayed in the extreme drought of 1955 by a yellow ribbon of bleached heath grass. At the junction where a branch runs north to Lurg Moor fortlet, scattered whin chips and wheel rutted rock are exposed, but as the road crests a ridge towards the fortlet the 15 feet (4.6m) wide metalled strip mounts a cambered agger 24 feet (7.3m) wide, which passes as an embankment across a localised marshy hollow just south of the fortlet. Beyond, the 15 feet (4.6m) metalled road reaches the south gate and passes via the north gate of the fortlet to run for a short distance towards the abrupt slope which the fortlet commands. Confined by the road, a rocky ridge to the west and the marsh to the south, is an annexe or wagon park. Sherds recovered from this area were Antonine (Robertson 1966: 198-199).

West of the T-junction the main road, a thin bank of whin chips c. 15 feet (4.6m) wide, surfaces a course of heavier cobbles on thin hard peat over rock. Beyond, in deeper peat the cambered profile 15 feet 6 inches (4.7m) resumes for some 100 yards (9.2m), inclining southward and climbing to pass beneath a fence close to a low scarp, NS 28927350, before obliquely terracing the descent north-west of Corlick Hill towards the series of hollowed peat tracks between Burnhead and Greenock. West of these it turns south-west, NS 28827345, a broad green track reaching for the ridge of Crawberry Hill, NS 28637318, where it turns west along the north edge of the hill to the moor fence, NS 28137325, less easily detected in deep heather. Traces fade by NS 28007330 on a northerly course, but north of a red brick ruin, NS 27737340, the road is recognised, swinging south-west to cross the watershed linking Crawberry Hill with Darndaff Hill. The Whitelees-Corlick Farm track sections a thin band of whinstone chips on subsoil, NS 27557325.

Just south of this point, obscured by a much expanded travelling turf dyke, NS 27507330, the road branches, the main trunk road continuing south-west, while a patrol road runs off to the west. It is just possible that the lengths of alternative road recorded above indicate a similar situation, although there they lie much closer together. It may be that we have traces of an earlier road.

The Patrol Road:

From the junction with the trunk road, around which lie several quarry pits, the patrol track runs south-west to the hill track to Darndaff Farm, NS 27427328, beyond which it

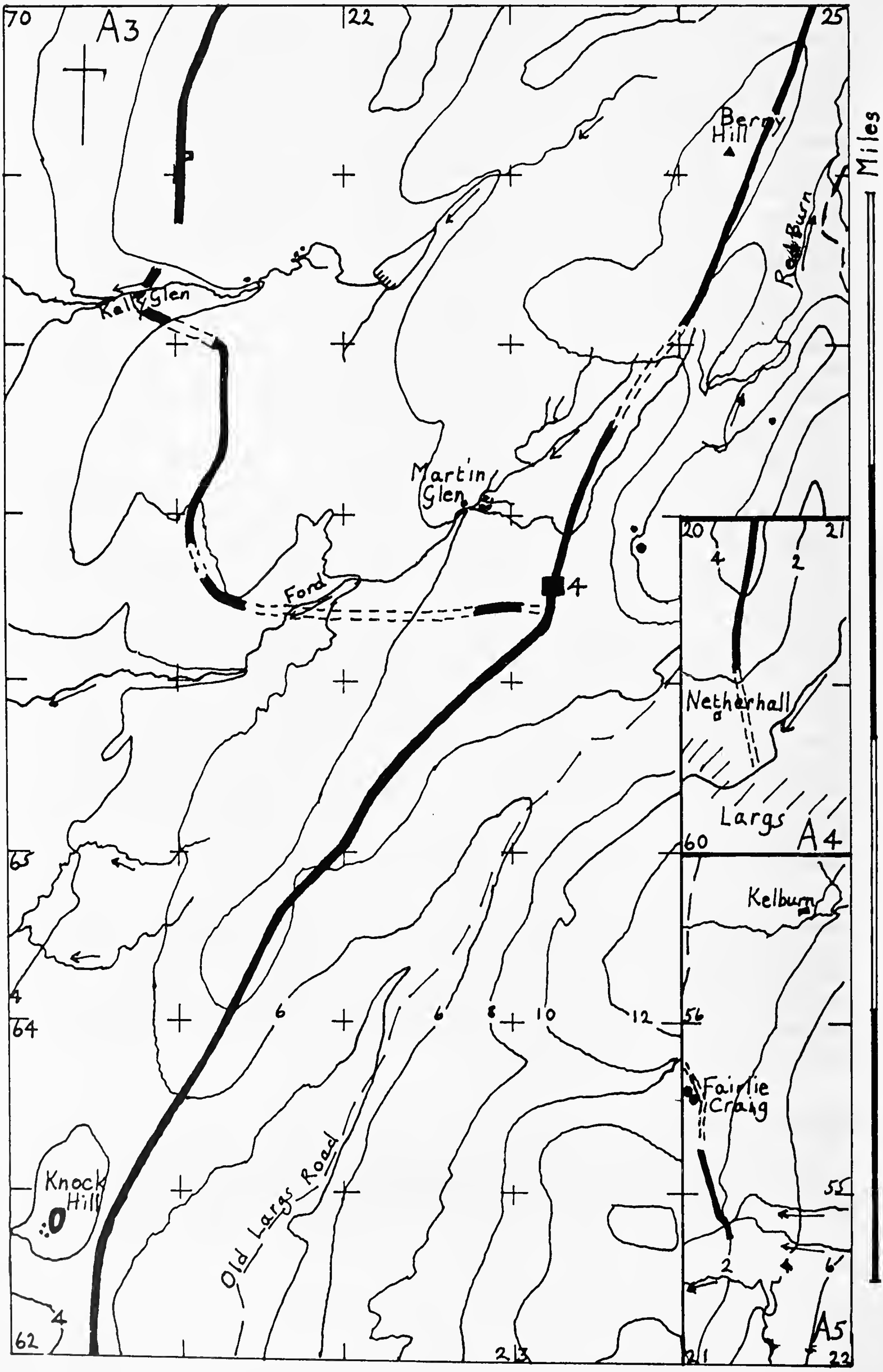
70
A3
22
25
Berry
Hill
Miles
Kelly Glen
Martin
Glen
Ford
4
20
21
4
2
Netherhall
Largs
60
A4
65
Kelburn
4
64
6
6
8
10
12
56
Fairlie
Craig
Knock
Hill
Old Largs Road
4
62
55
2
6
A5
21
3
22

Figure 3

Route A. North Section

Map A3

Patrol road joining the trunk road
south of Outerwards Roman fortlet (4)

Maps A4 and A5

Road lengths north and south of Largs

deflects to slightly north of west. From the west spur of Darndaff Hill it descends to the Old Largs Road, increasing from 15 feet 6 inches (4.7m) over level ground to an agger 17 feet (5.2m) wide by 1 foot 6 inches (0.5m) high over peat. Quarry pits follow the north side, east and west of the Old Largs Road which sections the agger, NS 26787372. Beneath the Killochend Farm road, NS 26697338, it enters Inverkip parish.

Round Hill is mounted, a faint trace only surviving, but increasing to a broad terrace overlaid by farm tracks as it deflects north-west round the hill shoulder to turn W.S.W. towards the south-east spur of Jock's Hill. Along this stretch the track is fugitive, NS 26377358 to NS 26057350, but takes advantage of a firm natural terrace and passes through two circular expansions, distinctively grass covered in rough moorland. Above the road, along the spur of Jock's Hill, are several quarry pits.

The road now tends farther north, centering the extreme west spur of the hill, NS 25687367, where it switches N.N.W. to cross the watershed below White Hill, the camber again in evidence. Here, at NS 25607375, it is sectioned by the hill track to Cornalees Bridge, where a thin spread of whin chippings 16 feet (4.9m) wide is laid on rocky subsoil. Over White Hill the eroded surface is spread with a scatter of whin chips, but on the north slope the agger causeways downhill over marshy ground, then appears as a cambered track, following north-west a slightly raised rock edge with quarry pits along its west side, and crosses a small stream, NS 25367400, which exposes cobbled foundations. Still slightly cambered, the road now effects a remarkable swing from north-west to slightly south of south-west, turning abruptly to run parallel with the trunk road. Clearly it was purposefully directed to this point. From it, Lurg Moor fortlet may be sighted. (Figure 2. Map A2).

Search in the vicinity has failed to locate obviously Roman traces, but to the immediate north-west of the pivot point, NS 25367400, is a low rock platform enclosed by a turf and stone wall some 4 feet (1.2m) wide and 47 feet (14.32m) north-south by at least 47 feet (14.32m) east-west, although stones along the south side extend to an overall 57 feet (17.39m). These, plus a stretch of walling to the east, and several stone piles to the west, may be near recent. Further stone walling encloses an area to the south and south-west. There is no trace of ditch. Nevertheless, in view of the anomalous behaviour of the road, the possibility of the site having been used, perhaps as a beacon platform, must be raised.

To the south-west the road heads for Scroggy Bank, and is elusive, sunk in marshland, but taking advantage of hard ground as occasional cambered lengths indicate. At the north foot of Scroggy Bank parallel lines of rushes may indicate side ditches leading to yet another example of graded cutting and embanking, NS 25107370. The ramp, embanked over marsh is 18 feet (5.5m) wide, and in drought the heath grass overgrowth bleaches white.

Over Scroggy Bank the road is terraced and descends the south face as a slightly embanked agger, to continue along the extreme east edge of a wet peat plateau, bending W.S.W. near the head of a small east-flowing stream, NS 25007345. Beneath the road, the moor can be bled by natural seepage assisted by culverting, as on the trunk road from Loch Thom (see below) and the approach to White Hill, north of the Clyde (Route D).

Along the east foot of a low scarp the road reaches the boundary wall of Shielhill, NS 24637322. Metal is visible in a drain north of the wall. To the south the faint camber ascends the east side of a peat ridge, and passing under a second stone wall swings abruptly south, NS 24367320, straight for the steep north face of the table land north of Hillside Hill. The slope is taken in a major continuous cutting and embanking. A long embankment curves into a cutting which carries the road uphill, swinging to south-east to south-west and again to south-east to maintain gradient. On the level surface the road is immediately lost in marsh.

From NS 24407280 to NS 24337268 the terraced camber is again traceable, with possible side ditches, passing some 50 yards (46m) west of a possible signal post tucked behind Hillside Hill, such that only the top of a 30 foot (9m) tower might be seen from the north, NS 24377268. A green circular mound, 2-3 feet (0.6-0.9m) high and 44 feet (13.4m) over each axis, contains a shallow rectangular hollow 25 feet (7.62m) east-west by 16 feet (4.9m). Round south and east rushes suggest a hidden ditch, while the north side is covered by a slightly hollowed terrace. A slight dip in the periphery faces the road.

Down the face of East Hill seasonal crop variation suggests that the route was along the east side of the hill stream, NS 24307268 to NS 23937208, to the Shielhill Glen road. Crop marking continues beyond, from the north-west corner of a field to the west scarp of a tongue of land round which the Shielhill Glen burn diverts, NS 23857198. Along the edge of this spur largely eroded by slip, road metal descends from NS 23847198 to the stream bed, NS 23717182, in a 1 in 6 graded south-west course.

On the south bank a concave rise is reduced to a 1 in 6 climb by a ramp of crushed sandstone which carries the 16 feet

(4.9m) wide road metal, which is traceable to NS 23637179 where it is overlaid by successive turf and stone dykes. A resurvey in 1988 with Mr. Tom Russell indicated that the road lies mainly beneath these until at a pronounced kink, NS 23417172, it edges to the north, and by the time the south-east wall of Inlie Hill plantation is reached the 27 feet (8.23m) overall road lies some 30 feet (9.0m) north of the dyke complex. Here the course is slightly north of west, whereas round Laxlie Hill to the south-west it is S.S.W. In between, a short stretch of heavily cobbled road runs from Broadlea Glen path, NS 22717143, to the bank of the Broadlea Glen burn, NS 22207135.

The road is next located at NS 21687024, clearing the woodland and swinging in a broad agger under the wall north of Laxlie Hill, where a hollowed track cuts through a mound of compact gravel on small cobbles. Terracing the north face of Laxlie Hill, the road fords a stream, NS 21236996, beside the bridge of the forestry road, which now overlies it to the south limit of the plantation, NS 21146983.

Now based on peat and overlaid by a minimum 4 inches (0.08m) of peat, the character changes to a mound of beaten clay, 6 inches (0.15m) thick at centre, sectioned by numerous minor rills, and 15 feet 6 inches (4.7m) to 17 feet (5.2m) wide on a terrace at least 18 feet (5.6m) wide. Side ditches, especially marked along the uphill east side, are 21 feet (6.4m) apart. Very light metal is driven into the clay surface, and in many sections is scarcely detected.

At NS 21056950 the S.S.W. course changes to south. Apparently cut by the road and adjacent on its east side, NS 21056915, is a small rectangular earth walled enclosure, the walls being based on flat stones.

Farther south, NS 20956900, just within Kelly Plantation are slight suggestions of a low mound enclosing a shallow hollow c. 14 feet (4.3m) in diameter. The road aligns slightly towards this point, to veer off again on the descent to the Kelly Burn. Side ditches now peter out, and quarry pits appear alongside. South of the fence, bounding rough pasture in rigged ground, NS 21006882, the road is lost but a wide stony ridge descends to the Kelly Burn, NS 20902634, below the gorge section. From almost opposite this, its lower end eroded, a 15 foot (4.6m) wide metalled road mounts obliquely W.S.W. the south bank. Above, NS 20736827, it returns E.S.E. to ascend the moor slope under 1 foot (0.3m) of peat, now a cambered ridge between slight ditch hollows, all fading on the upper slope and traced with extreme difficulty to the boundary of former Craigingour Wood, NS 21256798.

Beyond the east wall it swings south and runs on under peat to NS 21266744, a 15 foot (4.6m) wide swelling between drains 17-18 feet (5.2-5.5m) apart. A deflection S.S.W. directs it to the outer fence of Fardens Farm, NS 21226727 to NS 21186722, where it tends S.S.E. NS 21056691, towards Fardens, fording a stream to the north-west. It emerges to the north-east side of the farm road, and beyond the steading a green ridge between banks of rushes can be traced to NS 21306640, where it fades. It is heading for a ford on the Skelmorlie Water, NS 22306668. Towards this a hard track, mounded over the initial 50 feet (15m), runs from some 200 yards (185m) south of Outerwards fortlet on the trunk road (see below), but is lost at a minor stream crossing, NS 22606670.

From Criagingour to Fardens the road is crossed and mutilated by hollow ways and re-used as a near recent path known as the Pony Track. South of the ford north of Fardens, a hard cambered track fords the stream, NS 21036682, branching off to run direct to the hilltop south of Beithglass, crossing a stream, NS 20776689, by an 18 foot (5.5m) wide built-up ford. It enters enclosed ground on the hilltop between the present gate and a stile, and cannot be traced beyond the enclosure. Just to the south a rectangular crop mark was noted from Outerwards (in 1970).

The Main Trunk Road:

The trunk road leaves the junction, NS 27507330, a widely spread mound liberally stiffened with cobbles beneath the larger stones and spread turf of the travelling dyke. Kerbing is just visible. Much metal was possibly used at this point, to reduce the gradient and causeway a marsh to the south, where metal responds to the probe, 18 inches (0.46m) below the surface. Beyond the marsh, the cambered mound mounts through heather to NS 27307325, where as it begins a steeper run directly downhill it is lost; only the occasional clump of low much dissected and widely spread mound shows, but from the distance a broad yellow blaze is always perceptible through the heather.

Some 100 yards (92m) from the Old Largs Road, NS 26857290, the mound reappears north of Glen of Hecklemoor Burn bridge. West of the road a 22 feet (6.7m) wide mound curves in cutting and embanking to ford the burn, NS 26777282. The track down the south side of the stream is faint, but normally carries a broad yellow strip of vegetation.

At the side of Loch Thom, NS 26417267 a grey clay mound, red clay surfaced, with small metal driven in, is sectioned. During the extreme drought of 1984 the course was traced across the bed of the almost completely dry loch with Mr. Tom Russell, Ranger of Cornalees Nature Centre. At NS 25657220, the course aligns with the above, but turns from W.S.W. to south-west, a cambered mound partly under silt, partly of small stones in clay over peat, slightly terraced on the downside and 22 feet (6.7m) of camber over a 30 feet (9.0m) overall terrace, which rises towards the extreme south point of the smaller arc of a double bay, NS 25567210. Here the full road section of some 6 inches of small metal stiffened red clay, 21 feet (6.4m) wide, is sandwiched centrally between layers of peat 6-7 inches (0.15-0.18m) thick (Figure 4, section a). The course is S.S.W. The road is readily traced over a headland to find further exposure in deeply eroded bays, NS 25527183 and NS 25517179, a 23 foot (7.0m) wide lens of pink clay and small metal set centrally in peat, and 4-5 inches (0.08-0.13m) thick.

Beyond the extreme south headland a cambered ridge crosses the beach, NS 25417162 to NS 25327150 and passes beneath the south-west bank of the loch, where for some 80 feet (24.4m) it is again sectioned, centering the peat until it swings beneath the Cornaless road to rise on the moor beyond, NS 25277135 to NS 24857056, where it veers from S.S.W. to south. From NS 24807010 it is directed on a terrace on the north-east shoulder of Berry Hill, but is largely lost in peat. Where recognised, it is 24-25 feet (7.3-7.6m) wide and occasionally rises to as much as 2 feet (0.06m) above average ground level. Drains section a road of clay 18 feet (5.5m) wide in peat. Beyond NS 24807010 the road is edging a peat moss and lies under 18 inches (0.46m) of peat. Rivulets flowing from this reveal the road structure by cutting back in a series of miniature cascades into the clay of the downhill east edge. They may betray hidden culverts. Over the deeper moss the clay is laid on a layer of laid brown peat containing twigs, and separated from the basic black peat by small brushwood. Small 'peat cuttings' along the west side may be overgrown quarry pits, from which clay was dug.

From Berry Hill, NS 24406921, the course is direct to NS 24086832, changes more westerly to NS 23556737, then resumes course to the north end of the ridge west of Outerwards fortlet, NS 23226672. Round Berry Hill it is terraced. To the south it disappears under peat. Drains expose the clay, NS 24286880, but there are no surface traces between the head waters of the Skelmorlie Burn and Martin Glen Burn, NS 23806785 to NS 23556757. Nevertheless, drains and the probe show that the Roman engineers have directed their road along the extreme uptilted edge of sandstone strata which, to the south, outcrops as the Outerwards ridge. Their choice indicates not only remarkable skill but close knowledge of the land, for even in

Roman times the hidden strata lay beneath peat.

Clear of the moss the road clings to the series of outcrops north of Martin Glen, NS 23456725, to reach the fortlet at the north end of the widest outcrop. Along the ridge, clay is replaced by a metalled road 19 feet (5.8m) wide, based on crushed red sandstone lumps with finer sandstone on top. Quarry pits are frequent, especially along the west side, but are irregularly spaced and probably refer to repair, for a disused loop road west of the fortlet has been pitted.

South of the fortlet the road is flanked by a broad flat area which could have been used as a wagon park. Beyond this, over marshy ground, runs an embanked highly mounded causeway 21 feet (6.4m) wide, on a prepared strip 59 feet (18m) across, as it nears the stone boundary wall, NS 23086632. Quarry pits along this stretch again may refer to repair, for just south of the wall, as the road begins a slow curve towards Blackhousemoor ridge, drains section clay lens in peat.

In two sections, at and north of NS 23006620, the road has an 8 feet (2.4m) wide clay extension along the west side, like a parallel road, with but the slightest gap between. Similar localised extensions, 5-6 feet (1.5-1.8m) wide, occur at the Monadh Odhar (Route D), and beyond the March Burn (Route C). In each case the extension occurs at the top of a long steep slope. They may be temporary halts, for uphill traffic, perhaps for the removal of extra trace horses. However, it is but a short distance to the flat area south of the fortlet.

Analogies for the clay extensions are few. Multiple carriageways are recorded by Margary, as on the Chelmsford to Colchester and Birmingham to Gloucester roads (Margary 1973: 248, 288). Of extensions to one side of the road, however, only two cases are cited; a 4 feet (1.2m) extension on the Ixworth to Holme road, and a 9 feet (2.8m) extension near Heronbridge, which, however, was considered a possible earlier surface (Margary 1973: 259, 297). The hard shoulders at Ardoch (Breeze 1973) are scarcely analogous, nor the 3 feet (0.9m) clay bank along the road edge near Belshill (Price 1970: 31). We have recorded double cambering of Dere Street near Chew Green, but in view of the long history of this road it would be unwise to speculate without excavation.

A short distance south of the clay extension the road crosses a minor stream, which reveals a 12 feet (3.7m) wide light metal strip laid along the surface of the clay road, here 4 inches (0.08m) thick, 21 feet (6.4m) wide, above and below peat layers 6-7 inches (0.15-0.18m) thick.

Along Grassyards ridge quarry pits are more frequent.

Hollow ways have followed the general line west of the Roman road, but close with it along Outerwards ridge. Now over Grassyards they mutilate it, are joined by later tracks, and the road degenerates to a much dissected residual rutted camber 12 feet 6 inches (3.81m) wide, on an 18 feet (5.8m) terrace, NS 22006512. To NS 21586473 the road aims at the summit of Blackhousemoor, but now deflects along the east shoulder, regaining width to 18 feet (5.5m) on a 24 feet (7.3m) terrace. Drain sections, NS 21706485 reveal the usual clay road sandwiched in peat.

On the summit of Blackhousemoor a slight mound 70 feet (21.4m) over each axis, rises to a level surface 41 feet (12.5m) north-south by 39 feet (11.9m) containing a slight rectangular hollow 15 feet 6 inches (4.7m) by 14 feet (4.3m). The track branching to this from the Roman road may have serviced a small quarry cut into the south-east arc of the mound.

South of this point, just north of a stone wall, NS 21086368, a stream cutting back into the terrace has partially sectioned the road, here under 9 inches (0.2m) of peat. The clay mound 4 inches (0.08m) thick, lightly metalled on the surface, is here laid on a 2 inch bank (0.05m) of small metal driven into the peaty surface of soft clay subsoil. A drain to the east has a W-shaped profile.

Beyond the wall, the road is difficult to trace through rushes in formerly rigged ground, but has shown seasonally from Knock Hill as a crop mark. It crosses the extreme west corner of a field NS 20826329, fords a stream, NS 20816328, and runs to the natural terrace shouldering the wood east of Knock Hill. Despite the illusion of kinking, imposed by a later turf dyke and drain, the course is straight and the road is 24 feet (7.3m) wide on a 34 feet (10.4m) wide prepared terrace.

Within the wood the direction is more southerly, NS 20586270, and the road is partly removed by a large quarry. Now more extensively metalled over firm ground, it runs south-east gradually edging under the long boundary wall from Knock Wood to Brisbane Wood, NS 20466180, a mound 18 feet (5.5m) wide, with kerb stones occasionally seen along the east edge, on a 24 feet (7.3m) shelf.

As it enters the wood, NS 20466180, it is accompanied along the east side by a turf and stone bank. Fieldwork is impossible within the wood, but through the south 50 feet (15.25m) or so, a 27 feet (8.2m) wide mound can be traced with the bank continuing alongside. Beyond the woodland a stone wall runs centrally along the mound to NS 20166120, where the wall turns off south-east leaving a firm green track to continue through whin bushes to NS 20366137. Thereafter only a faint ridge through fields, and a bank of cobbling in a field drain, confirms the line, but south-east of Netherhall Farm, NS 20406076, the natural river terrace is interrupted by a broad ramp sloping to the carse fringe of the Noddesdale Burn. On the opposite bank a slight rise and break, NS 20456052, is possibly the last trace of road as it enters Largs. There a small Roman post may have been sited, in view of the Roman finds recorded (Newall 1976: 122). Since then, a Samian sherd has been found (Keppie 1986: 98), from the grounds of the Skelmorlie Aisle; previously, coins and clay tiles were found in the area just to the south.

Largs - Hunterston:

South of Largs no continuous road has been traced, but several lengths are suggestive, as undernoted:

(a) West of the Kelburn Estate, NS 21025663, a bridge carries the late 18th century road. The bridge is of earlier type and has been widened on the east from an original 18 feet (5.5m) maximum, the vestigial low parapet ledge surviving along the unmodified side. To the east the stream was originally forded by an earlier road. While the trunk road swings from NS 21115710 to NS 21065640, the earlier ran straight, its course preserved by footbridges to north and south, from NS 21075718 to NS 21005635. At NS 21145695, where culverts lie side by side, the earlier appears to be crossed by the curving track. To the north especially the earlier road rises as a cambered mound but is obliterated by the railway.

(b) Fairlie Castle covers a fording point of the Fairlie Glen burn. On this, three roads converge, viz. a track following the east side of a belt of woodland, NS 21325550 to NS 21305485; an improved terraced, embanked estate road, along the west side of the woodland; and an earlier road running south from beneath the end house of upper Fairlie, NS 21155555. At least 21 feet (6.4m) wide, this road passes obliquely down the north bank of Fairlie Glen. On the south bank an oblique approach, now hanging, restores the alignment. To the north the road is lost in rigged land. It is possible that the line is that of a faint track which develops as a wide hollow way, curving north-west round a circular enclosure on Craig Hill, NS 21105563, towards the coastal shelf.

(c) From south-west of Diamond Hill, NS 21605380, a terraced ridge road runs south, passing to the east of Black Hill homestead, NS 21615320, and tending S.S.E. to fade at NS 21785272. The road cambers on occasion, varies from 17 feet

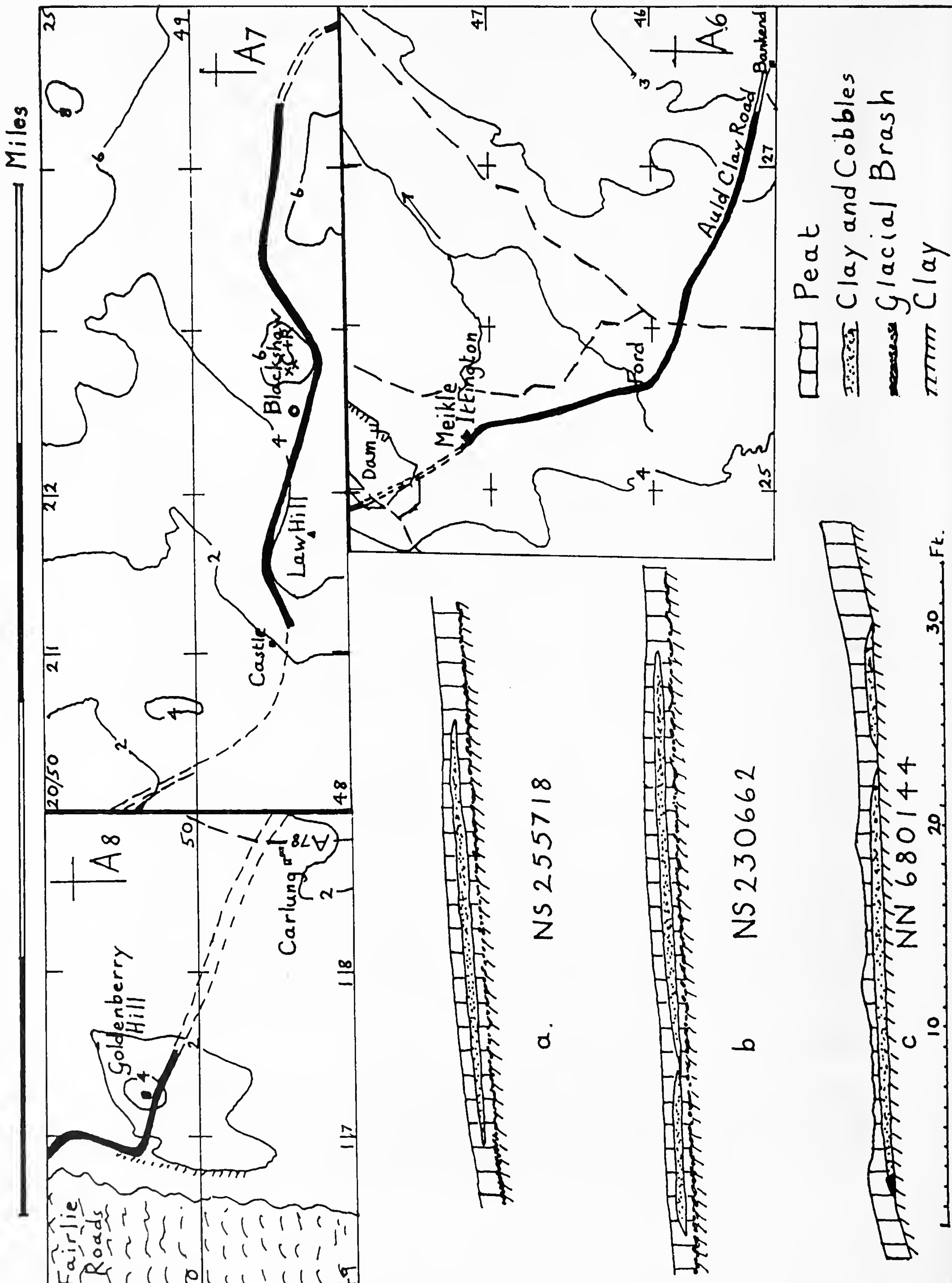
Miles
Fairlie Roads
Goldenberry Hill
Carlung
A8
A78
Castle
Law Hill
Blackshaw
A7
Dam
Meikle Itkington
Ford
Auld Clay Road
Bankend
A6
Peat
Clay and Cobbles
Glacial Brash
Clay
a.
NS 255718
b
NS 230662
c
NN 680144
10
20
30
Ft.

Figure 4

Route A. South section

Maps A6, A7 and A8

The Roman road from Bankend via Blackshaw, reaching for the coast at Hunterston (Brigurd Point) beyond Goldenberry Hill

Road sections

a) Loch Thom. Route A, north section.

b) Outerwards. Route A, north section.

c) Monadh Odhar. Route D.

(5.2m) to 24 feet (7.3m) in width, and follows a terrace 24 feet (7.3m) to 29 feet (8.8m) wide. This road could not be traced further, either north or south.

ROUTE A. SOUTH SECTION

The Auld Clay Road:

It seemed reasonable to assume that our road might well be aiming for the same point as the Avondale road. Sighting down valley from Loudoun Hill, we concluded that any road leading west must keep to the north side, nor were we unmindful of the early road improvements executed by the Earl of Loudoun.

A close study of maps and aerial photographs drew attention to a remarkable series of farm roads and tracks, converging on an artery which was not itself patently continuous. These roads and tracks lay to the west of the mapped 'Auld Clay Road' west of Bankend Farm.

Lee Ker (Ker 1900: 103-106) writes: "9th. There is another road branches off from the Byres Townhead of Kilwinning past Whitehurst and Ashgrove to the March of Ardrossan, leading past Bankhead and Laught to the Great Road betwixt Dalry and Saltcoasts". In Armstrong's map, 1774-75, the 'Great Road' had advanced towards Saltcoats only as far as the junction with the Diddup Farm track, and Ker's route 9 is shown in broken lines continuing past Ittington and Knockewart to join the B780, turnpiked in 1774 as far as Munnock, at the farm of Gill. An undisturbed length of 'Route 9' can be seen continuing north-west of High Whithurst, where the modern road bends towards Ashgrove House; and along the line of the Auld Clay Road, with which it coincides for a short distance, it does in fact run as far as the Dalry-Saltcoats road, although the modern Muirlaught lies beyond the 'Great Road', to the north. West of the turnpike, Armstrong's road runs closely parallel to but higher than the road we now describe.

The Auld Clay Road is aligned to pass to the north of Bankend Farm, and in the field to the west it survives as a raised stony ridge, 15 feet (4.6m) wide between the hedge bounding the south limit of the field and a ditch to the north, NS 27424530. Crossed by a mineral track, it widens as it crosses the next field to become the 'Auld Clay Road', NS 26954541, for a short distance now overlaid by a mineral road.

In its original state the road was a 17-21 feet (5.2-6.4m) width of cambered boulder clay, surfaced with a strip of light metal 12 feet (3.7m) wide, and standing in places 2 feet (0.6m) high. The full width may have been nearer 30 feet (9.2m), for a wide deep hollow way cuts into its south side.

Where recently ploughed, from NS 26504554 a scatter of small stones c. 15 feet (4.6m) wide passes along the north edge of a field. This is secondary, for side ditches 15 feet apart (4.6m) cut through the underlying clay mound. The road provides the line for a series of field boundaries as far as the Dalry-Saltcoats road, and is readily mistaken for a broad head rig. Beyond the main road it continues as a raised mound, but in places levelled and reduced in width by a field ditch and hedge towards NS 25624599, where it turns sharply to ford a streamlet, NS 25604610. Heavy blocks along the stream bed hint at a culvert, and the kerbed cobbling of the metal substratum, which is normal in the approach to streams, is visible in the field. Where best preserved to this point and sectioned by field ditches the clay mound is 18-21 feet (5.5-6.4m) wide. Beyond, aligned right-of-way gates and the Air Cover (the R.A.F. aerial survey) confirm the line, visible as a slight terrace crossing fields from NS 25504662 to run in with the modern track to Little Ittington. North-west, where the present road bends to avoid a reservoir, the original road continues via an iron gate to pass under the loch, NS 25104755, as a stony ridge 16 feet (4.9m) wide.

The route must then be uphill over the spur north of Knockewart. Surface traces have been ploughed out, but the Air Cover indicates faintly a track running to join a low terrace crossing a field, NS 24704828 to NS 24354890, where the earlier camber can be recognised beneath a scarped track crossing from Knockewart.

Thereafter the road is a boulder clay mound on a cobbled bed, and has a light central surface metal as seen in stream sections. Some 18 feet (5.5m) wide, it is disturbed by dyke and hedge along the north side and by a 12 feet (3.7m) wide hollow way along the south, cutting the prepared terrace, NS 24154845 to NS 23854853. So the road runs flanking North Hill on the north side and turning south towards Blackshaw Hill.

Beyond the parish boundary, NS 23384855, the road is re-used as an estate road, raised, scarped and 15-16 feet (4.6-4.9m) wide. Beneath, along the south side, the earlier road shoulders to a present width of 18 feet (5.5m) between ditch and dyke. Round the south shoulder of Blackshaw Hill the track runs into the 'old bridle road', NS 22504835, descending towards Law Castle round the north flank of Law Hill, and worn by use to a depth of 10 feet (3.1m) (Smith 1895: 22-23). Along the north side, NS 22504835, are several shallow quarry pits, more overgrown and smoother than the numerous mineral test pits which cover the area.

Beyond West Kilbride, air photographs (0008, f21.58, RAF:

2517; 032, 033, f21.58, RAF: 2517; 031, 032, f22.58, RAF: 2517) suggest very faintly a possible continuation along the east side of the B782 to pass beyond the A78, but there are alternative possibilities, as noted below:

(a) A line 'crossing' the A78 at a conspicuous bend, NS 19804966, and running west to pass Carlung and Thirdpart Farms on the north, NS 18885005.

(b) A much more probable line 'crossing' the A78 at NS 20064940, also passing north of Carlung, but running closely parallel to the south side of the road to Thirdpart, NS 19224982.

Mr. Park of Goldenberry Farm confirmed (in 1966) that this line was a former right of way to West Kilbride, and until recently was used as a path as far as the A78, the line still preserved by the aligned foot bridges over streams between Thirdpart Farm and the shoulder of Goldenberry Hill. There the road mounts the hill in a 1 in 5 gradient, a broad mound, expanding to clear the south flank of the hill as a 24-30 feet (7.3-9.2m) wide agger, passing the south end of an enclosure on the summit (see above).

At the south-west foot of the hill it is a 33 feet (10.1m) wide cambered road, running centrally along a 60 feet (18.3m) terrace. Parallel lines of mole hills, along the flanks and 33 feet (10.1m) apart, hinted at ditches (in 1968). West of the hill an almost sheer face is negotiated by cutting and embanking. The bold embankment sloping at a 1 in 5 gradient is eroded to reveal a mound of reddish sandy clay bedded on sandstone fragments over subsoil, and at the surface carrying but a thin scatter of metal.

Some 100 feet (30.5m) east of this carp, an anomalous flat slab and adjacent rock appear at the centre of the road. Excavation in 1970 showed these to be natural, so presumably the road mound originally covered them, as it must have covered the boulders along the road south of Carnsaigh Hill (Route B south).

West of the scarp the road is embanked across a narrow valley, passes over a whinstone rise, NS 17935034, and turns abruptly north under the boundary wall of Hunterston Estate, NS 17905039. Thence it runs north along the cliff edge, the Hawking Craig, close to which was found the Hunterston Brooch (Smith 1895: 20), falling from 250 feet (76.2m) to 50 feet (15.2m) in 480 yards (33.9m) on a terrace partly natural, partly artificial, overpassed by estate boundaries and the estate forest path, and overgrown by trees to NS 17975091. A descent of 1 in 5, as a 30 feet (9.2m) wide clay and earth ramped agger, heads west towards Hunterston raised beach, where it runs, a raised ridge of coarse grass through lighter pasture, to be lost just within the extreme south limits of Hunterston Power Station enclosure, NS 17905090. All to north and west has succumbed to recent grading.

Brigurd Harbour:

The most probable reason for the course of the road is that it was leading to a harbour or landing place.

On the beach from NS 18185184 a stob and wire fence runs W.N.W. towards the sea, following the footings of a 4-5 feet (1.22-1.54m) wide stone wall, possibly one of a complex of fishing yairs clearly visible on the air photographs (0029, 0030, F22, 58, RAF: 2517). But beyond these upper footings, where they run off diagonally to the north, NS 18005195, an underlying 10-12 feet (3.1-3.66m) wide mound emerges as a mole foundation 9 feet 6 inches to 10 feet (2.9-3.1m) wide, to run straight forward and disappear under low water. Along the south side runs a straight edged, almost cobbled, clear way at least 15 feet (4.58m) wide, and expanding towards low water mark.

Off Brigurd Point a deep-water berth facing towards Ailsa Craig is visible at low tide. The walls of rough 'square' blocks as those of the heaviest mole are 10 feet (3.1m) wide, and although utterly ruined by the force of the sea, evidence a strictly linear facing along the inner north wall. The east and west wall alignments, although disturbed, even to the foundation course in places, show clear signs of artificial construction; along the north and west side the floor has been tightly cobbled for some distance from the wall.

The harbour is 156 feet (47.52m) wide internally across the inner end, measured at its widest between the outer ends of chamfered corners, which provide a trapezoidal outline. Towards the entrance, at least 150 feet (45.72m) from the north end, but never seen above water, the harbour widens. At extreme low spring tide a wall was observed closing the berth, with roughly central entrance gap, but it appeared to abut the outer and inner walls, and the inner east wall continued past it in the direction of the mole. Thus the entrance footings appear to be a secondary construction.

At high tide, according to Admiralty Charts, the present remains lie under 2 fathoms (3.81m). It is highly improbable that the walls ever rose high enough to render the harbour practicable at any time approaching the present. It is not mapped by Watt in his survey of 1734 (Williamson 1856: map), although Pencorse (Portencross) is indicated. The point is indicated as Brig of Urd on Armstrong's map of 1775, and outlined by dots below his water line. No harbour was in operation by the 18th century.

In Gaelic, Brig means a heap or pile, like a peat stack, but the origin of the place name is probably Norse. (*Bryggja - ord;* Norse = landing place-point). It is interesting to note Halfway Cottage on the present coastal road to Portencross, for the Haaf Weg was the Sea Road by which early kings of Scotland made their final journey from Dalry to Portencross for burial in Iona.

Close to Portencross a major hollow way, perhaps a continuation of that which for some way has followed our road, descends the steep face to the coastal shelf.

Local tradition has little to add, but surprisingly Mr. Park of Goldenberry Farm pointed out, as the 'Roman Stone', a large block of rock standing near the centre of Hunterston sands several hundred metres north of the complex of yairs, which are possibly mediaeval. The rock itself yielded no information when inspected (in 1966), being totally barnacle encrusted.

With the entrance facing almost south towards the prevailing wind, Brigurd harbour might be used by forward sprit-rigged ships which could put about. Otherwise they would require to be warped out on sea anchors. Difficulty would be encountered by sail, but for the oar-propelled galley a straight run for the open sea is provided.

With a fleet patrolling the western approaches, the peculiar road running 'to the sea' and to a hill above Ardlamont (Route L) is feasibly Roman, as providing fast access to a signalling point from a ship run ashore on the shelving beach below Corra. With such security, landing stages up-river might be provided, perhaps at Largs, but a harbour at Dumbarton is extremely improbable.

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BREEDING PASSERINE COMMUNITIES OF FIVE DUNELAND HABITATS IN NORTH-EAST FIFE

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Introduction

This paper presents data on the breeding passerine communities and habitat characteristics of a consolidated duneland complex on Earlshallmuir - Tentsmuir, north-east Fife, during the breeding seasons of 1979 to 1981 inclusive.

Study Area and Methods

Earlshallmuir - Tentsmuir covers about forty square kilometres east of, and between, Leuchars and Tayport. About eighteen square kilometres is afforested, ten square kilometres is farmed, three square kilometres is airfield and ten square kilometres is mobile or stabilised duneland.

Study plots were set out to sample five habitats, as follows: semi-natural coniferous woodland (SNCon), commercial coniferous forest (COCon), birch/willow scrub (BWScr), mature birch/alder woodland (BAWoo) and dune grassland (DUGra) (see Table 1). All five plots lay between 5m and 10m above sea-level, and were on stabilised wind-blown sand of soil class 5 or 7 (Macaulay Institute for Soil Research 1969).

Random sampling of the vegetation in the plots was not possible, since two were impenetrable in several places. Instead the intersections of the 50m grid, set up in each plot for the bird census work, were used as sampling points. At each intersection, tree species and height, trunk diameter at breast height, height at which the canopy was most widespread, and percentage of ground covered by the canopy, were recorded within a 10m radius. Details of the field layer, including dominance, height, and percentage ground cover, plus presence of open water and brash were also recorded (Table 1).

The bird populations in each study plot were censused by the mapping method and analysed using standard techniques (I.B.C.C. 1969, B.T.O. 1976 and 1983). The only modification made was to include territories on the boundary of a study plot only if at least half the registrations lay within the plot. Copies of the resultant maps have been deposited with the British Trust for Ornithology for independent analysis and filing in the national archive.

Table 1. General habitat characteristics of study plots (all means ± s.e.).

Plot Code	Plot Name	Area (ha)	Dominant species of vegetation: Tree canopy	Shrub layer	Field layer	Ground layer
SNCon	Tentsmuir Point N.N.R. (part of)	19.7	Scots Pine Corsican Pine Lodgepole Pine Birch spp. Alder Willow spp.	Sea Buckthorn Birch spp. Willow spp.	Meadowsweet Rosebay Willowherb Creeping Willow Grass spp. Sedge spp. Brashings (1981 only)	Moss spp. Lichen spp. Conifer needles
COCon	Tentsmuir Forest (part of)	20.6	Sitka Spruce Scots Pine Lodgepole Pine	Absent	Fern spp. Rosebay Willowherb Rush spp. Grass spp. Sedge spp. Brashings	Moss spp. Lichen spp. Conifer needles Brashings
BWScr	Earlshallmuir birch/willow scrub	19.1	Birch spp. Willow spp.	Birch spp. Willow spp.	Creeping Willow Ragwort Rush spp. Woodrush Grass spp. Sedge spp.	Moss spp. Lichen spp.
BAWoo	Earlshallmuir birch/alder woodland	11.6	Scots Pine Birch spp. Alder Willow spp.	Birch spp. Willow spp.	Creeping Willow Ragwort Rush spp Woodrush Grass spp. Sedge spp.	Moss spp. Lichen spp.
DUGra	Earlshallmuir dune grassland (part of)	22.4	Absent	Absent	Creeping Willow Cross-leaved Heath Ragwort Rush spp. Woodrush Grass spp. Sedge spp.	Moss spp. Lichen spp.

Table 1. (Continued)

Plot Code	Plot Name	Age of woodland when censused (years)	Area of woodland (ha)	Area open (ha)	% open of entire area	Ratio of length of woodland edge (m) to woodland area (ha)
SNCon	Tentsmuir Point N.N.R. (part of)	⩽25	15.7	4.0	20.3	0.0064
COCon	Tentsmuir Forest (part of)	14-25	16.2	4.4	21.4	0.0019
BWScr	Earlshallmuir birch/willow scrub	Some parts 70-150; others <50	13.1	6.0	31.4	0.0208
BAWoo	Earlshallmuir birch/alder woodland	>230	7.2	4.4	37.9	0.0065
DUGra	Earlshallmuir dune grassland (part of)	Absent	0	22.4	100.0	-

Table 1: (Continued).

Plot Code	Plot Name	No. of trunks at each sample point	General height of tree cover	Height at which canopy most wide-spread	% of ground covered by the canopy	Foliage Height Diversity T.C.H.D.	C.W.H.D.
SNCon	Tentsmuir Point N.N.R. (part of)	25.27 ± 7.84	6.14 ± 0.43	4.19 ± 0.91	44.38 ± 5.10	0.4803	0.5858
COCon	Tentsmuir Forest (part of)	82.52 ± 14.97	6.00 ± 0.31	4.29 ± 0.41	88.64 ± 1.79	0.6678	0.8772
BWScr	Earlshallmuir birch/willow scrub	14.71 ± 3.74	6.79 ± 0.57	5.73 ± 0.60	56.82 ± 7.39	0.8845	0.9695
BAWoo	Earlshallmuir birch/alder woodland	9.69 ± 2.49	5.58 ± 0.66	3.75 ± 0.60	34.17 ± 4.08	0.7585	0.9003
DUGra	Earlshallmuir dune grassland (part of)	0	0	0	0	0	0

Notes:

T.C.H.D. : Diversity of general height of tree cover) in 0.5 m intervals and including brash
C.W.H.D. : Diversity of general height of canopy's maximum width) as a layer; following Moss (1976).

Diversity Index is the Shannon-Weaver: $H' = -\Sigma p_i \log_e p_i$; where p_i = proportion of the total population represented by the ith species, and the sum taken over all the species.

Results

The main characteristics of the vegetation in each plot are presented in Table 1.

The highest passerine population densities were in the birch/alder woodland (BAWoo), followed by the commercial coniferous forest (COCon), the semi-natural coniferous woodland (SNCon), the birch/willow scrub (BWScr) and the open grassland (DUGra) (Table 2). This ranking remained consistent over the three years studied. The indices of diversity were largely inconsistent between plots and years, although the dune grassland plot (DUGra) was always lowest.

Only five passerine species were recorded holding territory on this plot during the years 1979 to 1981; the dominant species were Skylark *Alauda arvensis* and Meadow Pipit *Anthus pratensis*. The Skylark and Meadow Pipit populations increased over the study period, probably as numbers recovered following the hard winter of 1978/79 (Table 2).

Three species, Robin *Erithacus rubecula*, Willow Warbler *Phylloscopus trochilus* and Chaffinch *Fringilla coelebs*, accounted for at least 50% of the population of the birch/willow scrub (BWScr), and together with the Wren *Troglodytes troglodytes* and Blue Tit *Parus caeruleus* made up 75% of the bird community by 1981 (Table 2).

These five species were also dominant in the mature birch/alder woodland (BAWoo), but here the colonial Starling *Sturnus vulgaris* was more abundant than elsewhere, and exploited the many holes in the old standing timber. The Wren population increased over the study period, probably recovering from the effects of the 1978/79 winter. In each year, Starling and Chaffinch made up at least 50% of the birch/alder (BAWoo) bird community.

In the semi-natural coniferous woodland (SNCon) the Chaffinch was always the most abundant species, followed by either Robin or Coal Tit *Parus ater*, and Goldcrest *Regulus regulus* or Willow Warbler. Wrens were first recorded in 1981.

In the commercial coniferous forest plot (COCon) the same six species as in the semi-natural coniferous plot (SNCon) were usually dominants in the community. The Chaffinch was always the most abundant and, with the Robin, Willow Warbler or Coal Tit, accounted for at least 50% of the population each year (Table 2).

Table 2: Densities (territories/20 ha) of the breeding passerines in the five study plots in each year.

Study Plot	SNCon			COCon			BWScr			BAWoo			DUGra		
Year	79	80	81	79	80	81	79	80	81	79	80	81	79	80	81
Skylark	-	-	-	-	-	-	-	-	-	-	-	-	8.9	13.0	13.0
Meadow Pipit	-	-	1.0	-	-	-	-	-	0.5	-	-	-	0.9	6.3	6.3
Wren	-	-	3.0	2.9	6.8	11.2	1.0	3.1	8.4	6.9	10.0	21.0	-	-	-
Dunnock	-	2.0	1.0	1.9	2.9	2.9	-	-	-	-	1.7	-	-	-	-
Robin	11.0	12.0	22.0	9.7	17.0	30.0	5.2	9.4	12.0	3.5	8.6	14.0	-	-	-
Wheatear	-	-	-	-	-	-	-	-	-	-	-	-	0.9	0.9	-
Blackbird	4.1	1.0	3.0	9.7	2.9	4.9	1.0	1.0	1.0	1.7	3.5	1.7	-	-	-
Song Thrush	2.0	2.0	3.0	1.0	2.9	4.9	-	0.5	1.0	1.7	0.9	-	-	-	-
Mistle Thrush	-	-	-	-	-	-	-	-	0.5	-	-	0.9	-	-	-
Sedge Warbler	-	-	-	-	-	-	-	-	-	1.7	1.7	1.7	-	-	-
Willow Warbler	11.0	6.1	8.1	15.0	12.0	11.0	16.0	16.0	20.0	18.0	17.0	19.0	-	-	-
Goldcrest	-	5.1	14.0	6.8	14.0	14.0	-	-	-	-	-	-	-	-	-
Spot. Flycatcher	-	-	-	-	-	-	-	-	-	1.7	1.7	-	-	-	-
Long-t. Tit	1.0	3.0	2.0	1.9	3.9	1.0	3.1	2.1	-	5.2	3.5	-	-	-	-
Coal Tit	7.1	17.0	14.0	17.0	17.0	25.0	3.1	3.1	3.1	2.6	8.6	6.9	-	-	-
Blue Tit	-	2.0	2.5	1.0	1.9	1.0	5.2	6.3	9.4	10.0	12.0	10.0	-	-	-
Great Tit	2.0	1.0	3.0	-	1.0	1.9	4.2	3.1	3.1	5.2	6.9	8.6	-	-	-
Treecreeper	2.0	2.0	3.0	1.9	1.9	2.9	2.1	1.0	3.3	1.7	6.9	3.5	-	-	-

Table 2: (Continued)

Study Plot	SNCon			COCon			BWScr			BAWoo			DUGra		
Year	79	80	81	79	80	81	79	80	81	79	80	81	79	80	81
Jay	-	1.0	1.0	0.5	0.5	-	1.0	-	1.0	-	-	-	-	-	-
Carrion Crow	0.5	1.0	1.5	-	-	-	0.5	1.0	1.0	0.9	1.7	1.7	0.4	-	0.4
Starling*	-	-	-	-	-	-	2.1	1.0	4.2	81.0	64.0	60.0	-	-	-
Chaffinch	33.0	33.0	34.0	30.0	26.0	31.0	23.0	15.0	24.0	36.0	26.0	35.0	-	-	-
Siskin	-	2.5	1.5	-	1.5	1.0	-	-	0.3	-	-	0.4	-	-	-
Linnet	-	-	-	-	-	-	1.0	-	1.0	-	-	-	-	-	-
Redpoll	2.0	2.0	1.5	5.8	2.4	1.9	3.1	2.1	2.6	5.2	3.5	3.5	-	-	-
Crossbill	-	2.0	-	-	-	0.5	-	2.1	-	-	-	-	-	-	-
Bullfinch	-	1.0	2.0	-	1.0	1.0	-	-	1.6	-	-	0.9	-	-	-
Yellowhammer	-	-	-	-	-	-	1.0	-	-	1.7	-	1.7	-	-	-
Reed Bunting	-	-	-	-	-	-	-	-	-	-	-	-	0.9	-	0.9
Totals/20 ha	77	97	123	105	114	146	73	67	98	186	179	190	12	21	21
Totals/km²	385	485	615	525	570	730	365	335	490	930	895	950	60	105	105
Passerine Species Richness	11	18	19	14	17	17	16	15	19	17	17	17	5	3	4
Diversity Index (H')	1.775	2.192	2.302	2.140	2.329	2.220	2.185	2.233	2.296	1.911	2.199	2.134	0.923	0.777	0.864

* Starling: Population estimate from census of apparently occupied nests.

Discussion

Winter Mortality

The winter of 1978/79 was the most severe recorded since 1962/63 and followed a series of particularly mild winters. The severe weather led to high mortality amongst many resident bird species, and consequently their populations were low at the start of the 1979 breeding season (Cawthorne and Marchant 1980). The population data here (Table 2) suggest that the following species had been most affected: Skylark, Meadow Pipit, Wren, Dunnock *Prunella modularis*, Robin, Goldcrest, Long-tailed Tit *Aegithalos caudatus*, Coal Tit, Blue Tit, and Treecreeper *Certhia familiaris*. These small passerines are particularly susceptible to prolonged extreme weather conditions, since their ratio of surface area to body volume is such that they lose heat faster than larger species (Cawthorne and Marchant 1980, Elkins 1983).

Habitat Structure

The bird censuses (Table 2, Figure 1) show that the poorest habitat for breeding passerines was the open dune grassland (DUGra), which had a simple habitat structure (Table 1). The habitat supporting the highest population densities was the mature birch/alder woodland (BAWoo), with its more complex structure (Table 1). The bird populations of all five study plots were low in 1979 following the hard winter, but there were increases over the next two seasons, the increases being greatest on the grassland plot (DUGra) and least in the mature woodland (BAWoo).

Semi-Natural and Commercial Coniferous Woodland

The present study allows a comparison between the passerine communities of semi-natural (SNCon) and commercial (COCon) coniferous woodland of similar ages on similar sites near sea-level (Table 1). The longest habitat edge was in SNCon, which had a greater variety of tree species and a shrub layer. In COCon, tree cover was denser and more uniform and less light reached the ground. The proportion of non-passerine species which attempted to breed in COCon was the lowest of all five plots (Table 3). This may reflect the closed nature of the habitat, which would make access difficult for the larger birds. In each study year, COCon supported higher densities of passerines than did SNCon, but held a similar number of species and had a similar diversity index.

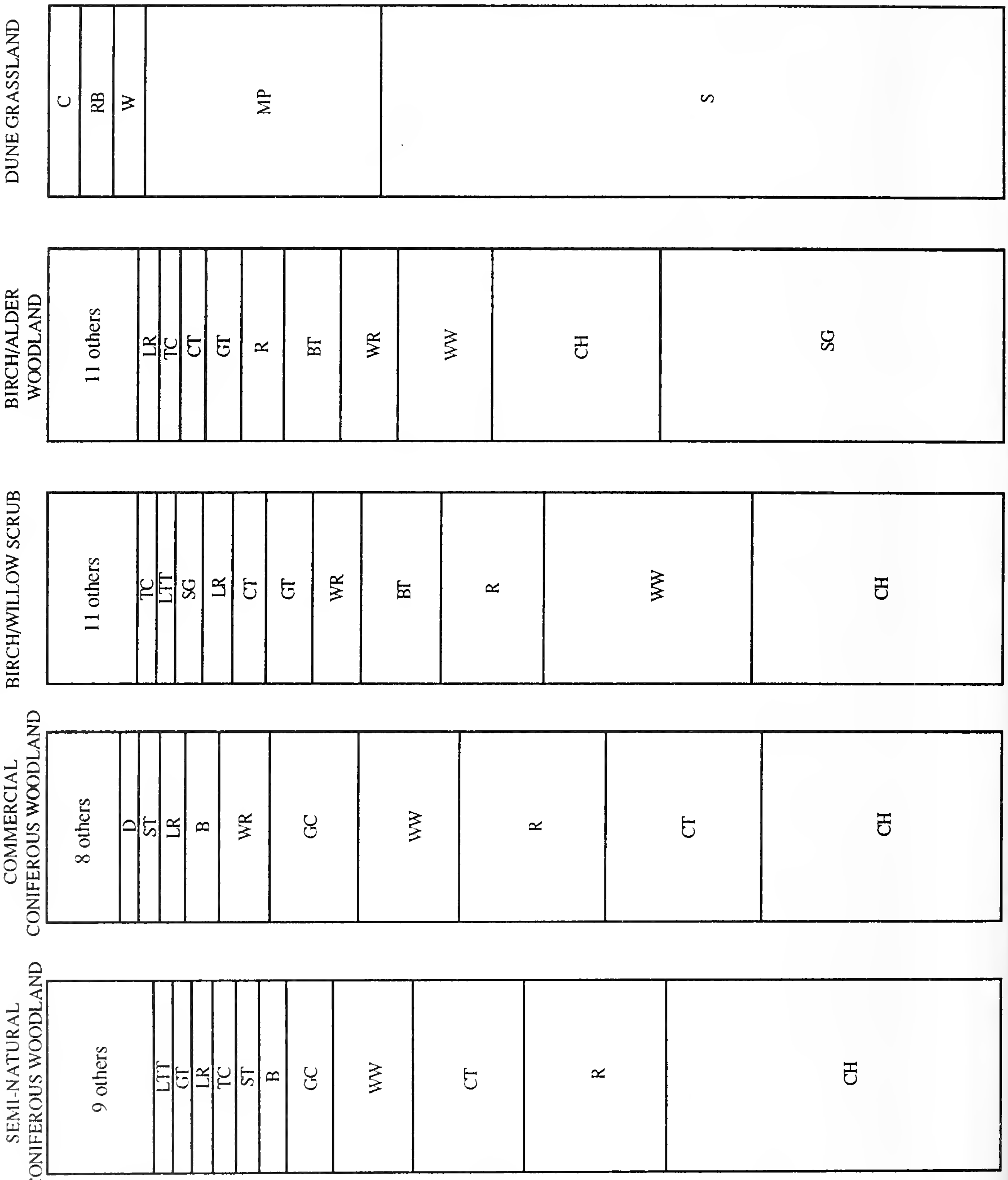
Of the species common to both plots, population densities for all but the Blue Tit, Great Tit *Parus major*, Treecreeper, Jay *Garrulus glandarius*, Chaffinch, Siskin *Carduelis spinus*, and Bullfinch *Pyrrhula pyrrhula* were higher in COCon. Five species, - Wren, Dunnock, Goldcrest, Blue Tit and Jay - were absent from SNCon in 1979 or 1980, but were present in all three years in COCon. This could be an effect of the 1978/79 winter, with some populations being eliminated and then recovering over the next one to three years in a sub-optimal habitat (SNCon) but remaining at a depressed level and then increasing from that point in an optimal habitat (COCon) (Glas 1960). This is almost certainly the case with the Wren, the re-establishment of which in SNCon coincided with the creation of brashing piles (a favoured habitat) following forestry operations in the winter of 1980/81 (Moss 1976, 1978a, 1978b; Dougall 1983).

Sea-level Woodlands

The present study is one of the few to have been conducted in sea-level woodlands, so comparable data are therefore scarce. Innes (1976) also worked in Tentsmuir Point National Nature Reserve and censused part of the present SNCon plot in 1976. In the two to four years between his study and the present one, SNCon had become more wooded in character, especially at its seaward edge, as the trees colonised the dunes. The Meadow Pipit population fell from six pairs to one pair, but there were increases in the populations of scrub and woodland species, such as Wren, Song Thrush *Turdus philomelos*, Goldcrest, tits, and Bullfinch. In addition, Treecreeper, Carrion Crow *Corvus corone*, Siskin and Crossbill *Loxia curvirostra* held territory for the first time in 1979/81. No species were lost as territory-holders between the times of the two studies.

Jones (1966) reported the results of a study on the bird populations of successional stages across a sand-dune system in north-west Anglesey. His census in 1964 came one year after the severe winter of 1962/63. Of his six successional stages, five were represented in the present study (II = DUGra, III-IV = SNCon, and V-VI = COCon). On dune grassland (DUGra), he recorded a total of 82 territories/km^2 for the only two species present (Skylark and Reed Bunting *Emberiza schoeniclus*); in Fife, the total for five species ranged from 60 to 105 territories/km^2. In semi-natural conifers (SNCon), the Fife total ranged from 385 to 615 territories/km^2 for a total of 20 species, compared with 144 territories/km^2 for 11 species in Anglesey. In commercial conifers (COCon), the corresponding figures were, in Fife, 525 to 730 territories/km^2 for 18 species and, in Anglesey, 217 territories/km^2 for 10 species. Clearly then, the Fife study plots during 1979 to 1981

FIGURE 1 : THE COMPOSITE BREEDING PASSERINE COMMUNITY OF EACH STUDY PLOT, 1979-1981



(Each named species has a relative abundance value over 3 years of at least 2%. See Table 2 for species).

Names of Bird Species listed in Figure 1.

B - Blackbird
BT - Blue Tit
C - Carrion Crow
CH - Chaffinch
CT - Coal Tit
D - Dunnock
GC - Goldcrest
GT - Great Tit
LR - Redpoll
LTT - Long-tailed Tit
MP - Meadow Pipit
R - Robin
RB - Reed Bunting
S - Skylark
SG - Starling
ST - Song Thrush
TC - Treecreeper
W - Wheatear
WR - Wren
WW - Willow Warbler

Table 3: The numbers of non-passerine (NP) and passerine (P) species in the breeding communities of the five study plots.

Study area:	SNCon		COCon		BWScr		BAWoo		DUGra	
	NP	P	NP	P	NP	P	NP	P	NP	P
1979	7	11	6	14	12	16	8	17	6	5
1980	10	18	6	17	11	15	10	17	8	3
1981	11	19	5	17	12	19	13	17	7	4
Total 1979-81	11	20	8	18	13	22	13	21	8	5
%NP:%P 1979-81	35 : 65		31 : 69		37 : 63		38 : 62		62 : 38	

supported much higher densities than those of approximately the same developmental stages on Anglesey in 1964, with both periods coming after severe winters.

Another study in a different area of Wales in 1967-68, four to five years after the severe winter of 1962/63 (Jones 1973), found no breeding passerines on mobile dunes. Population densities of Skylark and Meadow Pipit on stable dune-slack areas, however, were similar to those in Fife (totals of 83 territories/km^2 in each of 1967 and 1968, and totals of 49.5 to 97 territories/km^2 for 1979-81, respectively).

On the Lincolnshire coast, Morgan (1978) found densities on duneland scrub of up to 1,425 territories/km^2 in 1974, while in Lothian da Prato (1985) reported densities of 2,250 territories/km^2 in mixed inland scrub; both studies were in diverse habitats with many nesting and feeding situations.

Other Scottish Studies

The important work by Moss (1976, 1978a, 1978b, Moss *et al.* 1979) on songbird populations in conifer habitats is of restricted relevance to the present study, since his work involved different tree species and ages, usually in inland and upland situations, and not following a hard winter. Moss investigated *inter-alia* a semi-natural plot of Scots Pine *Pinus sylvestris* in Speyside, at an altitude of 250-290 m.a.s.l., with a ground layer of heaths and a shrub layer of Juniper *Juniperis communis*, which allows a comparison to be made between the breeding passerines of native Caledonian Forest in Speyside and semi-natural coniferous woodland (SNCon) (largely pines) at sea-level in Fife.

Fewer passerine species were recorded in Speyside (12, compared to 20 in Fife) but the population densities and diversity index values were similar (385 to 471 territories/km^2 in Speyside, 385 to 615 territories/km^2 in Fife; H'= 2.109 to 2.210 in Speyside, 1.775 to 2.302 in Fife). In planted Scots Pine study areas in Speyside, Moss found densities of 151 to 215 territories/km^2, which were less than half those of the semi-natural pines in Fife. In planted Scots Pines in lowland Dumfriesshire, Moss found that density and species-richness were also low (208 to 340 territories/km^2 for 6 to 8 species). It therefore appears that semi-natural areas of Scots Pines can support a higher density and species-richness of passerines than can planted Scots Pines, and that there are some similarities in the breeding passerine communities in areas of semi-natural Scots Pines at sea-level and in upland relict natural stands. However, some commercial coniferous woodlands have breeding passerine population and species-richness values well above those of natural or semi-natural conifer stands, although they are never so high as are reached in areas of deciduous scrub (da Prato 1985, Morgan 1978, and this present study).

Summary

On four woodland and one grassland study plots in north-east Fife during the breeding seasons of 1979 to 1981, the lowest population densities of passerines were on open dune grassland (DUGra) and the highest were in mature birch/alder woodland (BAWoo). High population diversity index values were found in semi-natural coniferous woodland (SNCon) and birch/willow scrub plots (BWScr).

Following the severe winter of 1978/79, there was a gradual increase in the breeding populations on all plots over the three study years. This increase was greatest on the dune grassland (DUGra) and least in the mature deciduous woodland (BAWoo).

On dune grassland (DUGra) two species, Skylark and Meadow Pipit, were dominant. In the four woodland communities, Chaffinch, Robin, Willow Warbler and Coal Tit or Blue Tit were dominant.

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FEEDING MORPHOLOGY AND BEHAVIOUR IN THREE-SPINED STICKLEBACKS FROM TWO SCOTTISH SITES WITH DIFFERENT INVERTEBRATE FAUNA

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Introduction

Two distinctive forms of the Three-spined Stickleback *Gasterosteus aculeatus* form *leiurus* have been identified in North American lakes. These are the so-called limnetic and benthic forms, the names alluding to their distribution within a single lake habitat. Limnetic sticklebacks feed on the organisms that live in the water column, i.e. zooplankton, whereas benthic sticklebacks feed on the organisms that live on the substrate, i.e. benthos (Larson 1976; Lavin and McPhail 1985, 1986). In association with this difference in diet, limnetic sticklebacks possess narrower gapes and longer, more numerous and more closely spaced gillrakers than benthic sticklebacks. Such characteristics increase the efficiency of both types of sticklebacks when feeding on their respective food (Zaret 1980; Lavin and McPhail 1985, 1986). This present study describes comparable morphological differences between sticklebacks from two Scottish populations which are specialized for feeding on benthic and zooplanktonic prey, and attempts to identify the behavioural processes responsible for the differences in diet between the two forms.

FOOD AVAILABLE AND FOOD EATEN IN NATURAL HABITATS

MATERIAL AND METHODS

Description of the Study Sites

The two sites studied (Loch Lomond and Balmaha Pond) differ markedly in a number of characteristics. Loch Lomond is much larger (71.1 km^2) than Balmaha Pond (0.001 km^2) and is dominated by open areas, whereas Balmaha Pond is dominated by submergent and emergent vegetation. The sampling station of Loch Lomond was a shallow water site (40-50 cm deep) in the Mill of Ross Bay (NS 368968), which has a bed of thick submergent aquatic littoral flora (10 cm high). The sampling station of Balmaha Pond included the whole Pond except an area of c.8 m in diameter in the centre of the pond. This area has a deep muddy bottom which was difficult to sample with the equipment available.

Food Available

The zooplanktonic and benthic prey available in the two study sites were sampled quantitatively in June 1986. Five water samples (4 litres each) and five core samples (30 cm in diameter) were taken randomly from each station as representative samples of zooplankton and benthos respectively (see Ibrahim 1988, for more details of sampling). Individual items of zooplankton and benthos were identified, counted and recorded as numbers per 20 litres of water and 0.35 square metres of the substrate respectively. Because the potential food of sticklebacks consisted of both benthos (estimated as a number/0.35m^2) and zooplankton (estimated as a number/20 litres water; see above), and to allow an electivity index to be used (see below), it was necessary to standardize the two estimates into a common scale. The number of zooplankton held above a square metre of a substrate was therefore calculated (this was possible since the water depth above the substrates was known). Following this, the bulk of each food type from benthos and zooplankton found on or above a square metre was expressed in terms of weight units (Ibrahim 1988).

Food Eaten

Forty sticklebacks from Loch Lomond and thirty from Balmaha Pond were caught in the morning (at 10 am, just before collecting samples of the food available) at the end of June 1986. They were killed immediately by benzocain anaesthesia and preserved in 70% alcohol. Stomach contents were removed, identified as either zooplanktonic (including those organisms that inhabit the water column exclusively) or benthic (including those organisms that inhabit the lake bed partially or totally). The bulk of each taxon from the zooplankton and the benthos was then calculated, by the same method used in calculating the bulk of the food available in the habitat (i.e. on the basis of weight units, see above). The number of units of a given food type in the stomachs examined was then expressed as a percentage of the total units of all food types in the diet. The number of stomachs in which at least one prey item of a given food type occurred was expressed as a percentage of the total nmber of occurrences of all food types. The percentages of the overall bulk zooplankton and benthos in each stomach were also calculated.

Electivity indices of the food types, based on the bulk data (Cock 1978) of both the food eaten and the food available, were calculated using the relativized electivity index (E*) of Vanderploeg and Scavia (1979):

$E^* = [W_i-(1/n)] / [W_i+(1/n)]$ where:

W_i = Chesson's (1978) alpha coefficient = $(r_i/p_i)/\Sigma (r_i/p_i)$
r_i = the proportion of food type i in the diet
p_i = the proportion of food type i in the environment
n = the number of food types available in the environment

The E* values have a possible range from +1 (positive selection) to -1 (negative selection). An E* value of 0 indicates absence of selection, i.e. the food type was eaten in a proportion similar to that in the environmental sample.

Because the index is sensitive for the food types that are rarely eaten (Lechowicz 1982), the electivity values of food types which formed less than one per cent of the diet were not calculated. In addition, to reduce the effect of sampling error, absence of electivity was arbitrarily set at values ranging from -0.1 to +0.1 (instead of 0), all values above +0.1 indicating positive selection and those below -0.1 indicating negative selection (Tompkins and Gee 1982).

DATA ANALYSIS

A χ^2-test was used to compare the total numbers of zooplankton and benthos sampled from Loch Lomond and Balmaha Pond. A Mann-Whitney U-test was used to compare the percentage of zooplankton and benthos eaten by Loch Lomond and Balmaha Pond fish.

RESULTS

Food Available

As Table 1 shows, Loch Lomond contributed a higher density of zooplankton than did Balmaha Pond. The predominant zooplanktonic prey in Loch Lomond were copepods and in Balmaha Pond were chydorids. In contrast, Balmaha Pond had a greater density of benthos than Loch Lomond, although the density of benthos in Loch Lomond was still high. In both sites the predominant benthic prey were Chironomid larvae and Oligochaeta. These differences between the two sites are stable over time.

Food Eaten

Sticklebacks from Loch Lomond consumed more zooplankton (94.75%) than did Balmaha Pond fish (19.25%, $P < 0.001$, U-test) and those from Balmaha Pond consumed more benthos (80.75% in Balmaha Pond sticklebacks as opposed to 5.25% in Loch Lomond sticklebacks, $P < 0.001$, U-test). The diet of Loch Lomond fish consisted mainly of copepods (Table 2); chydorids, *Bosmina coregoni*, and *Daphnia* sp. contributed little to the total bulk,

Table 1

Number of zooplankton (per 20 litres of water) and benthos (per 0.35 square metres) available in Loch Lomond and Balmaha Pond during June 1986.

Food Type	Loch Lomond	Balmaha Pond	
Zooplankton:			
Copepods	158	5	
Chydorids	24	14	
Bosmina coregoni	36	2	
Daphnia sp.	3	0	
Nauplii	8	0	
TOTAL ZOOPLANKTON	229	21	***
Benthos:			
Ostracoda	1	1	
Chironomid larvae	56	350	
Chironomid pupae	2	7	
Ceratopogonoid larvae	23	15	
Oligochaeta	121	75	
Caddis larvae	30	7	
Insecta nymphs	19	4	
Subimagines	2	1	
Asellus aquaticus	6	0	
Gastropods	0	6	
TOTAL BENTHOS	260	466	***

*** = P <0.001, χ^2-test.

Table 2

Percentage composition by occurrence and by bulk of food eaten by Loch Lomond and Balmaha Pond fish in their natural habitats.

Food Type	% Occurrence		% Bulk	
	Lomond	Balmaha	Lomond	Balmaha
Zooplankton:				
Copepods	22.4	17.6	81.50	8.55
Chydorids	11.6	14.0	0.40	3.30
Bosmina coregoni	14.7	0	0.89	0
Daphnia sp.	7.0	0	0.82	0
Benthos:				
Ostracoda	1.5	7.7	0.11	0.71
Chironomid larvae	12.4	21.1	5.35	64.80
Chironomid pupae	8.5	10.5	1.53	7.34
Ceratopogonoid	7.7	3.5	2.76	0.84
Oligochaeta	0.8	1.4	0.30	1.13
Caddis larvae	0.8	2.1	1.73	0.79
Insecta nymphs	1.5	4.9	0.18	3.32
Subimagines	1.5	4.2	0.43	1.82
Asellus aquaticus	0.8	0	0.30	0
Gastropods	0	1.4	0	1.58
Fish eggs	3.9	3.5	1.84	2.77
Algae, Plant-Tissues and Sand	3.1	5.6	0.40	0.60
Unidentified	1.5	2.1	1.30	2.77

although they occurred in many of the stomachs. Of the available benthos, Chironomid larvae and pupae, Ceratopogonoid larvae and fish eggs were found in small amounts in the stomachs of sticklebacks from Loch Lomond. The other food types listed in Table 2 occurred only in few stomachs and contributed little to the diet. The food of Balmaha Pond fish consisted mainly of Chironomid larvae; Chironomid pupae contributed a little to the total bulk, although they occurred in a considerable number of stomachs. The other benthic food types listed in Table 2 occurred in few stomachs and contributed little to the total bulk. Of the available zooplankton, copepods and chydorids were eaten by most of the fish and made a major contribution to the total bulk of food in the stomach. Algae, plant tissues and sand particles were occasionally found in the stomachs of sticklebacks from both sites, but more commonly in those from Balmaha Pond.

Electivity Indices as a Measure of Food Preference

Table 3 shows that, among zooplankton, copepods were positively selected by both Loch Lomond and Balmaha Pond fish. Chydorids were positively selected by Balmaha Pond fish but were rarely eaten by Loch Lomond fish (i.e. their electivity indices were not calculated; see above). Among the benthos, Chironomid pupae were positively selected by both Loch Lomond and Balmaha Pond fish. Subimagines were taken in proportion to their abundance by Balmaha Pond fish, but were rarely eaten by Loch Lomond fish.

DISCUSSION

The above results show clear differences in the food available in Loch Lomond and Balmaha Pond. Loch Lomond has a higher density of zooplankton than Balmaha Pond, which in turn has a higher density of benthos. This is reflected in difference in the diets of sticklebacks from these two sites. Sticklebacks from Loch Lomond feed predominantly on zooplankton, whereas those from Balmaha Pond feed predominantly on benthos. However, Balmaha Pond fish still take some zooplankton despite its scarcity in the pond. The diets of Loch Lomond and Balmaha Pond fish are therefore comparable to those described for limnetic and benthic sticklebacks respectively (e.g. Lavin and McPhail 1986), with limnetic fish feeding on zooplankton and benthic fish feeding on benthos.

Both Loch Lomond and Balmaha Pond fish show positive selection for zooplankton in their natural habitats, so sticklebacks from Balmaha Pond are probably forced to consume larger quantities of benthos in their natural habitat because

Table 3

Electivity indices of the most common prey of zooplankton and benthos eaten by Loch Lomond and Balmaha Pond fish in the natural habitats.

Food Type	Loch Lomond	Balmaha Pond
Zooplankton:		
Copepods	+	+
Chydorids		+
Benthos:		
Chironomid larvae	-	-
Chironomid pupae	+	+
Ceratopogonoid larvae	-	
Oligochaeta		-
Caddis larvae	-	
Insecta nymphs		-
Subimagines		0
Gastropoda		-

+ = positive selection

- = negative selection

0 = random selection

of the low availability of zooplankton. This preference for zooplankton can be explained by the fact that zooplanktonic prey have a number of visual properties, such as colour and movement, which enhance their attractiveness to sticklebacks (Ibrahim 1988). In addition, feeding on zooplankton gives higher energetic return than feeding on benthos (see below).

HABITAT CHOICE

MATERIAL AND METHODS

The Fish

The sticklebacks used in this test were caught in Loch Lomond (37-40 mm; S.L.) and Balmaha Pond (37-39 mm; S.L.) during June 1986 and were kept in the laboratory for about four weeks, during which time daily meals of *Tubifex* worms were provided. One day before the test, the fish were marked by red plastic rings on two of their dorsal spines to increase their visibility to the observer. These marks did not appear to affect the behaviour of the fish.

The Habitats

Two adjacent habitats of Loch Lomond were used in this study; vegetated habitat (silted sand covered with a sward of dark green submergent aquatic plants dominated by *Lobelia dortmanna* growing to c.5 cm) and sandy habitat (bare sand). The water (25-30 cm deep) was clear and quiet enough for the observer to witness the movement of the fish.

The Enclosure

A trapezoidal enclosure (0.3x3.0x2.5 m) made of green netlon mesh (6 mesh/cm^2) was used to surround the two habitats. Its diagonal matched the boundary between the habitats, so it defined two symmetrical areas (2.06 m^2 each) of vegetation and sand. This shape of enclosure was chosen to allow an observer behind the small base to see the fish in any part inside the enclosure.

Test Protocol

At the beginning of the test, the enclosure was fixed in place and a single stickleback (deprived of food for 24 hours to ensure stomach evacuation; Beukema 1968) was gently released inside the enclosure on the boundary of the two habitats. The movement of the stickleback was observed for 20 minutes after it began sculling using the pectoral fins (typical of undisturbed stickleback). The times spent in the vegetated habitat as opposed to the sandy habitat, and on the lake-bed (within 5 cm above the substrate) as opposed to the water column, were recorded (to the nearest one second) on a tape recorder. At the end of each test the stickleback was caught by a hand net, killed immediately by benzocain anaesthesia, and preserved in 70% alcohol for later stomach analysis. The test was then run on the next fish. Overall, seventeen fish from Loch Lomond and ten fish from Balmaha Pond were tested within three days. Two of the Loch Lomond fish were lost from view during the test and were therefore used only for stomach analysis.

Food Availability and Food Consumption in the Enclosure

At the end of the tests, five water samples (4 litres each) and two core samples (30 cm in diameter) were taken from each habitat to represent zooplankton and benthos respectively. The potential prey were identified to the lowest possible taxon. It was assumed that feeding did not cause a significant depletion in the amount of food available, because the amount of food eaten by the fish was extremely small compared to that available in the habitats. The stomach contents of the tested fish were identified as either zooplankton or benthos, and the fish were then classified as having fed on zooplankton, benthos or both.

DATA ANALYSIS

A Mann-Whitney U-test was used to compare the time spent in vegetation and sand, and in the water column and lake bed, by Loch Lomond and Balmaha Pond fish. A χ^2-test was used to compare the number of zooplanktonic and benthic prey individuals in vegetated and sandy habitats, and the number of fish from Loch Lomond and Balmaha Pond which fed on zooplankton, benthos or both.

RESULTS

As Figure 1a shows, Loch Lomond fish tended to spend more time in the vegetated habitat then did Balmaha Pond fish, which in turn spent more time in the sandy habitat, but these differences were not significant. Regarding the use of water column and lake bed (Figure 1b), sticklebacks from Loch Lomond spent significantly more time in the water column than did Balmaha Pond fish, which used the lake bed preferentially.

The vegetated habitat contained a greater density of food types and had a much higher density of benthic prey than did the sandy habitat (Table 4). However, the number and density of zooplanktonic prey were similar in the water column of the two habitats. The number of sticklebacks feeding on zooplankton,

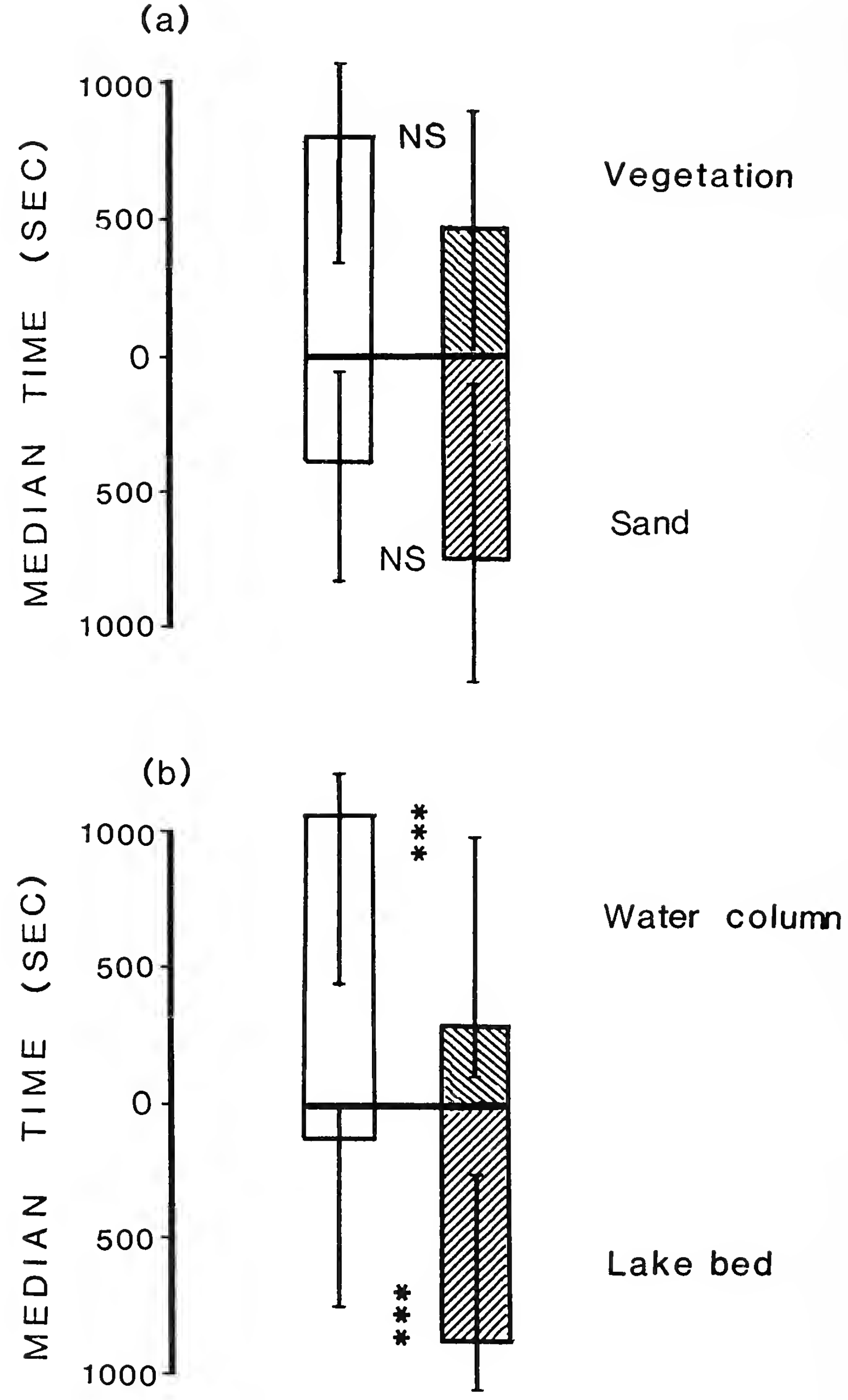

Figure 1

Median and range of time (in seconds) spent by Loch Lomond (blank column) and Balmaha Pond (lined column) fish in vegetation v sand (a) and in water column v lake bed (b).

*** = P <0.001, NS = Not significant, U-test.

Table 4

Number of prey types and density of zooplankton (number per 20 litres of water) and benthos (number per sample; i.e. 0.141 square metres) sampled from vegetated and sandy habitats inside the feeding enclosure in Loch Lomond.

	Vegetated	Sandy	
Number of Zooplanktonic Prey Types	6	5	
Density	80	60	NS
Number of Benthic Prey Types	12	5	
Density	61	22	***

*** = $P < 0.001$, NS = Not significant, χ^2-test.

Table 5

Number of fish which fed on zooplankton, benthos, or zooplankton plus benthos inside the feeding enclosure in Loch Lomond.

Food Types	**Loch Lomond (n = 17)**	**Balmaha Pond (n = 10)**	
Zooplankton	15	5	
Benthos	0	3	NS
Zooplankton + Benthos	2	2	

NS = Not significant, χ^2-test.

N.B. Some of the expected numbers in the data were less than 5; these increase χ^2 value and the chance of a significant result. Since the outcome of this test was not significant, these values have not invalidated the test.

benthos or both did not differ significantly between Loch Lomond and Balmaha Pond (Table 5).

DISCUSSION

The results of this test show that, when feeding in the same area, Loch Lomond fish use the water column more than Balmaha Pond fish, which in turn use the lake bed. Sticklebacks from Loch Lomond are exposed to higher predation risk than those from Balmaha Pond (Ibrahim 1988); they are adapted to predation risk to the extent of having longer dorsal and ventral spines (Plate 1). This difference in the exposure to predation risk may explain the reduced tendency of Loch Lomond fish to use sandy, unsheltered habitat.

Although sticklebacks from Balmaha Pond feed predominantly on benthic prey in their natural habitats, sticklebacks from both sites feed on zooplankton in the enclosure where the density of such food (and the density of benthos) is high. Feeding in the water column is more profitable than feeding on the lake bed, because sticklebacks handle zooplankton prey more efficiently (Ibrahim 1988). However, Balmaha Pond fish feeding in Loch Lomond still spend more time on the lake bed than do Loch Lomond fish. Paszkowski and Tonn (1983) have shown that Yellow Perch *Perca flavescens* select their foraging areas on the basis of naturally preferred sites and not on the basis of immediate profitability. Thus the preference for a habitat, on the basis of its current profitability, can be overridden by the preference for the general type of foraging location itself. In agreement with this, Balmaha Pond fish naturally inhabit dense vegetated habitats whereas Loch Lomond fish inhabit open habitats.

MORPHOLOGY OF THE FEEDING APPARATUS

MATERIAL AND METHODS

Information about the morphology of Loch Lomond and Balmaha Pond fish was obtained by examining 25 fish chosen at random from those used in the previous experiment. Standard length (distance from the tip of the snout to the base of the caudal peduncle) and gape size (the distance between the two side-angles of the mouth) were measured. Gillraker number, length and spacing were measured on the anterior section of the first gill arch of the left side of the head. Gillrakers were counted and then the longest three were measured, as the distance from the ventral margin of the base to the tip, and the mean was obtained. The widest three spaces between the gillrakers (adjacent to the longer gillrakers) were measured, as the space between the base of a given gillraker and the one

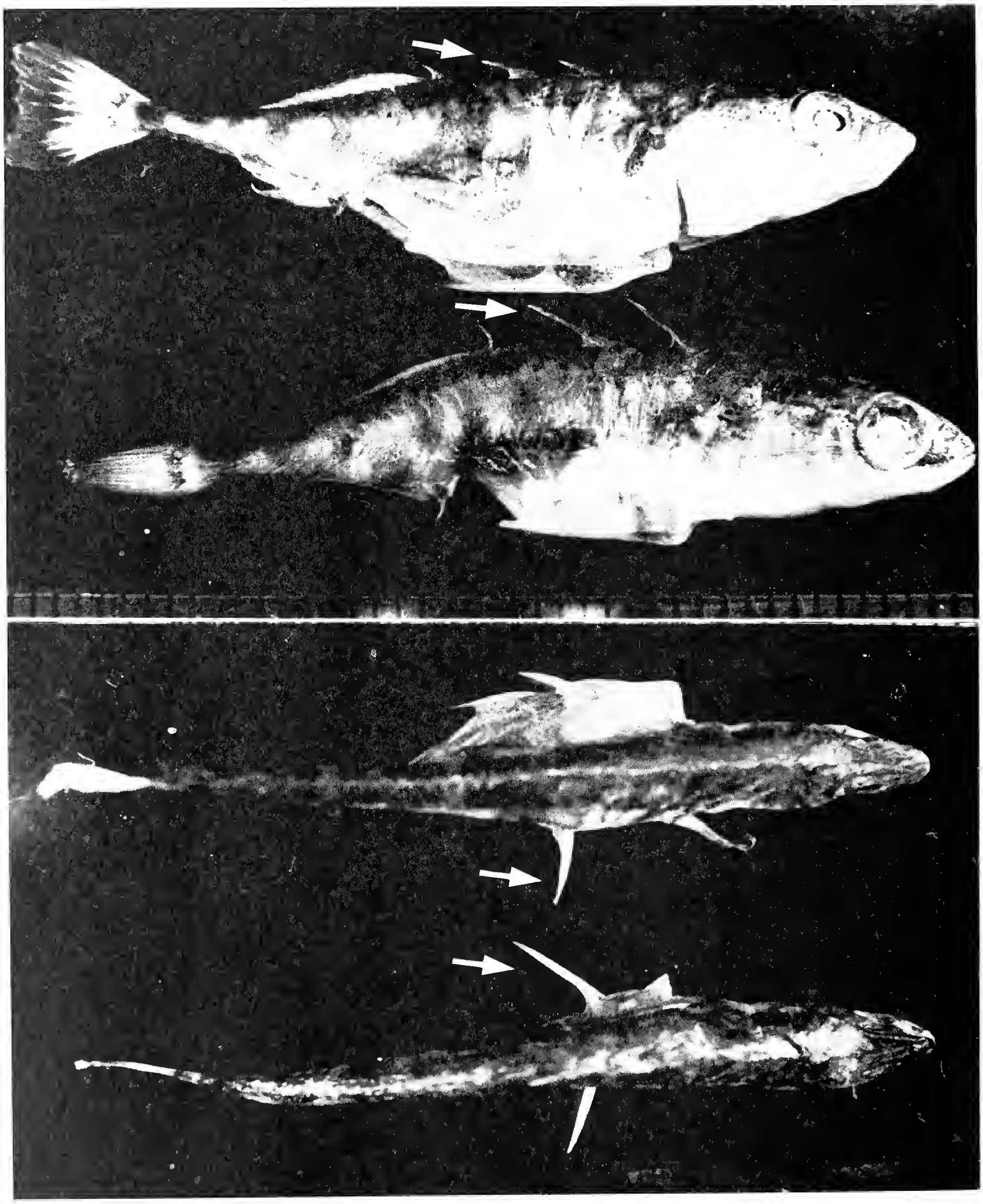

Plate 1

Dorsal spine (a) and ventral spine (b) length
of Loch Lomond (L.L) and Balmaha Pond (B.P.) sticklebacks.
(Photographs of preserved fish after removal of stomachs).

next to it, then the mean was obtained. All the above measurements were taken to the nearest 0.05 mm, except that of standard length which was taken to the nearest 0.5 mm.

Gillraker measurements as well as gape size were found to correlate with the standard length of the fish. This raises the possibility that any difference between populations might be an indirect result of any differences in overall body size rather than a direct result of ecological condition. Therefore, in addition to the absolute values, relative values expressed as proportions of the standard lengths were calculated. Data on counts of gillrakers were not standardized in this way since they stabilize in fish longer (S.L.) than 3 cm (Penczak 1965), and all fish tested were longer than 3 cm. A Mann-Whitney U-test was used to compare Loch Lomond and Balmaha Pond fish in various morphological parameters under investigation.

RESULTS AND DISCUSSION

The data on various morphological features of Loch Lomond and Balmaha Pond fish are presented in Table 6. Loch Lomond fish were larger and had narrower gapes than Balmaha Pond fish. Gillraker number and length were higher in fish from Loch Lomond than in fish from Balmaha Pond, and the distance between the gillrakers was wider in Balmaha Pond fish, for both absolute and relative measurements.

These differences may be related to differences in food available. The larger body size of Loch Lomond fish may be a result of the more profitable food they eat (i.e. zooplankton; see above) or may reflect the adaptation of fish to predation pressure, since larger body size may function as a defensive mechanism against predators (Moodie 1972). The wider gape of Balmaha Pond fish may enable them to exploit benthos (the major food type in their natural habitat) more efficiently than Loch Lomond fish. The narrower gape and more numerous, longer and closer gillrakers of Loch Lomond fish may enable them to take zooplankton more efficiently (Zaret 1980).

GENERAL DISCUSSION AND CONCLUSIONS

The results of these comparisons have shown that sticklebacks from Loch Lomond and Balmaha Pond encounter a different array of potential food items. Sticklebacks from Loch Lomond, which feed predominantly on zooplankton in their natural habitat, feed preferentially in the water column, whereas those from Balmaha Pond, which feed on benthic prey in their natural habitat, prefer the lake bed. Sticklebacks from Loch Lomond are more efficient than those from Balmaha Pond at harvesting zooplanktonic prey (Ibrahim 1988). This may arise

Table 6

Median absolute and relative values of various morphological features of Loch Lomond and Balmaha Pond fish. The range is given in parentheses (all measurements in mm).

Parameters	Loch Lomond Fish	Balmaha Pond Fish	
Standard Length	40.50 (36-44)	36.0 (33-39)	***
Absolute Gape Size	2.700 (2.4-3.1)	3.400 (3.0-3.9)	***
Relative Gape Size	0.066 (0.06-0.07)	0.091 (0.08-0.11)	***
Gillraker Number	19.00 (17-21)	16.00 (15-19)	***
Absolute Gillraker Length	0.816 (0.66-1.00)	0.600 (0.53-0.80)	***
Relative Gillraker Length	0.020 (0.017-0.024)	0.016 (0.011-0.019)	***
Absolute Gillraker Spacing	0.174 (0.15-0.20)	0.200 (0.18-0.25)	**
Relative Gillraker Spacing	0.004 (0.003-0.005)	0.005 (0.004-0.006)	***

** = P <0.01, *** = P <0.001, NS = Not significant, U-test.

because of differences in morphology of feeding apparatus (narrower gapes and more numerous, longer and closer gillrakers), but may also be the result of differential practice of handling. Thus, in respect of their feeding apparatus morphology and diet choice, sticklebacks from Loch Lomond and Balmaha Pond resemble respectively the 'limnetic' and 'benthic' sticklebacks described by Lavin and McPhail (1986). Despite the differences in feeding, habitat and morphology, fish from both sites, when given a choice, prefer zooplanktonic prey to benthic ones, but only those from Loch Lomond are able to feed on such prey in their natural habitat.

Summary

Food preference, habitat choice and morphology of feeding apparatus were studied in sticklebacks from two sites in Scotland (Loch Lomond and Balmaha Pond) naturally exposed to different invertebrate fauna. Although both fish groups show a positive selection for zooplankton, they have different diets that reflect the type of food available to them. This difference results from both differential micro-habitat choice and differences in feeding apparatus (specifically gape size, and number, length and spacings of the gillrakers).

Acknowledgements

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A SIMPLE METHOD FOR SAMPLING THE INVERTEBRATE FAUNA OF SUBSTRATES OF VARIOUS DEGREES OF STRUCTURAL COMPLEXITY

By A.A. IBRAHIM and F.A. HUNTINGFORD
Department of Zoology, University of Glasgow

Introduction

Quantitative sampling of bottom fauna of shallow standing water is the basis for many ecological studies. The methods of sampling used are very diverse, ranging from using a grab sampler (Ekman 1911) or open-ended core cylinder (Dunn 1961) to using just a hand-net sweeper (Welch 1948). Each of these methods suits a particular type of substrate. The grab sampler, for example, is successful on soft substrates (eg. mud) but not on hard ones (eg. thick beds of vegetation). Similarly, a hand-net sweeper can be used on smooth substrates but not on rough ones (eg. stones).

It is quite common, however, for a sampling programme to include a wide variety of substrates differing in their structure, and in such a case more than one type of sampler has to be employed. This variation in sampling methods creates inaccuracy in the results because of the different sampling errors resulting from each method. To overcome this problem, a hydraulic sampler (or airlift, Aarefjord 1972) has been used, but this has a major drawback since it requires expensive equipment and operation. This paper describes a simple sampling method, based on lifting parts of the substrate using a tray sampler, which can be used to sample substrates of various types.

Construction of the Tray

The construction of the sampling tray was as follows (Plate 1):

1. The tray bottom (Plate 1a) was cut to the desired size of 35x35 cm from a sheet of transparent perspex, one centimetre thick.

2. Four perspex rods (Plate 1b) (2x2 cm) were cut to a height of 5 cm and were glued to the sampling tray bottom at each corner, 5 cm from the edges.

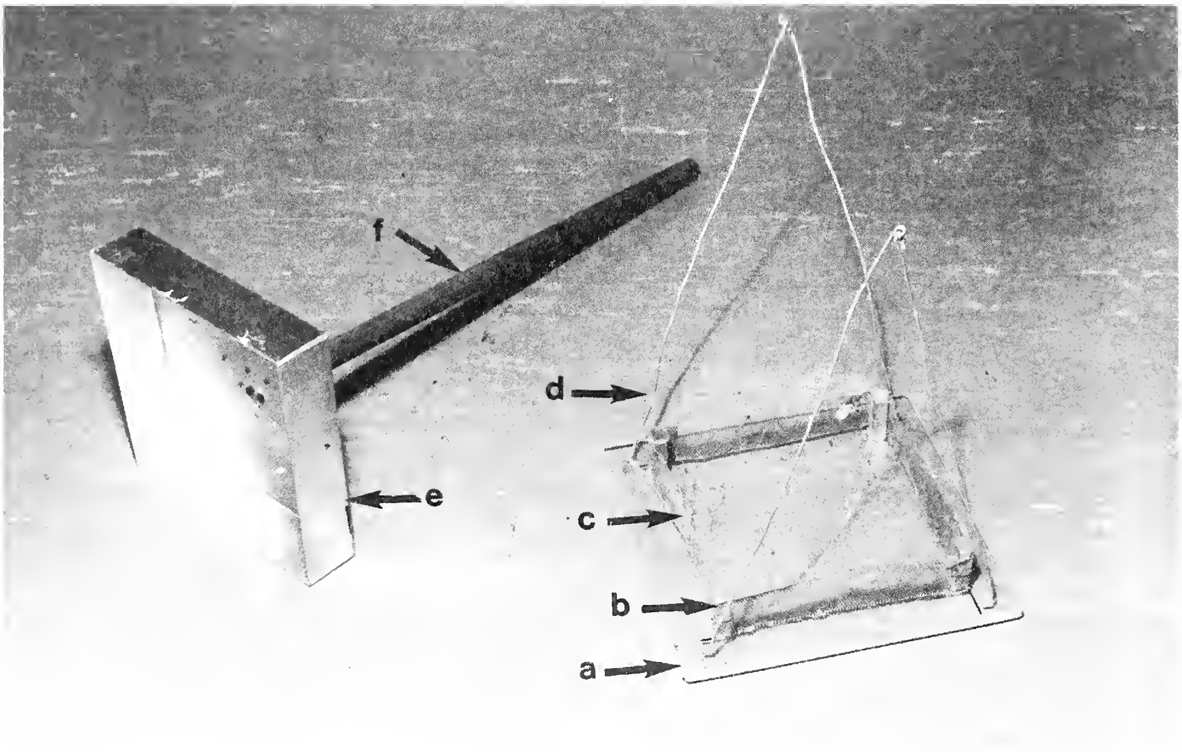

Plate 1

Construction of the Tray sampler

a = Tray bottom

b = Perspex rod

c = Tray wall

d = Tray handles

e = Tray cover

f = Tray-cover handle

3. The tray walls (Plate 1c) were made of metal mesh (16 mesh/cm^2; 5 cm in height) glued to the rods; they thus enclosed the main body of the sampling tray; an area of 25x25x5 cm.

4. The tray handles (Plate 1d) were made of strong wire and were fitted to the bottom by drilling a hole at each corner. The handles were 50 cm in height to enable efficient lifting of the tray.

5. The tray cover (Plate 1e) was fabricated from an Aluminium sheet, with dimensions of 26x26x6 cm, which is large enough to completely cover the main body of the sampling tray. This cover also had holes drilled on its top, to avoid displacement of the invertebrates by the water current created during covering the tray.

6. The tray cover was also provided with a wooden stick handle one metre long, (Plate 1f) and fixed at the center by nails, to ensure easy placement of the cover over the tray.

Operation of the tray

The trays were placed in a hole of the appropriate size (c. 35x35x8 cm), dug in the substrate using a long armed hoe, and then filled with the excavated material and associated fauna. The surface of the tray was made level with that of the surrounding substrate. The tray was marked with a buoy and left in place for three weeks, by which time it was packed with invertebrates. Following colonization, each tray was covered with the cover to protect the sample, and was then lifted with the help of the attached handles.

Specimen results

The tray sampler was used to sample benthic communities of vegetated (thick bed of submergent aquatic plants dominated by *Lobelia dortmanna* which grew to an even height of c.5 cm), stony and sandy substrates of Loch Lomond (Camas an Losgainn Bay, NS 373957) during June, July and August 1985. A small area (i.e. 40-60 m^2) from each substrate was sampled. Water depth above these substrates varied between 80 and 96 cm.

A representative sample was worked out after taking a number of sub-samples. The representative sample was defined by stabilizing both the number of taxa and their abundance over the successive sub-samples (Elliott 1983). The first criterion was assumed to be met when three successive sub-samples brought no more new taxa into the total list (Elliott 1983). The second

Table 1: Number of invertebrates found in each sub-sample and total invertebrates in samples taken from a vegetated substrate of Loch Lomond during June, July and August 1985.

Invertebrates	June Sub-samples						July Sub-samples						August Sub-samples						Total Individuals			
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		June	July	August	
Caenis sp.	20	16	31	26	14	NS	1	6	2	4	2	NS	0	0	0	0	0		107	15	0	**
Ephemerella ignita	16	13	8	5	12	NS	2	1	3	2	2	NS	0	0	0	0	0		54	10	0	**
Emphemera danica	1	0	2	4	0	NS	5	9	1	7	5	NS	0	1	0	1	0		7	27	2	**
Other Ephemeroptera	1	0	2	1	0	NS	4	2	2	0	1	NS	4	3	2	1	3	NS	4	9	13	NS
Leuctra hippopus	9	10	4	3	5	NS	2	2	3	8	1	NS	27	15	13	23	24	NS	31	16	102	**
Coleoptera adults	9	13	10	6	10	NS	2	3	1	7	3	NS	3	3	3	5	6	NS	48	16	20	**
Coleoptera larvae	24	93	20	23	9	**	12	19	3	8	3	**	23	10	24	20	16	NS	169	45	93	**
Asellus aquaticus	7	2	8	4	2	NS	0	3	2	3	0	NS	2	6	4	3	1	NS	23	8	16	*
Chironomid larvae	17	31	25	29	26	NS	16	16	16	15	12	NS	268	158	166	69	82	**	128	75	743	**
Chironomid pupae	4	8	9	4	2	NS	1	2	0	1	3	NS	16	8	9	11	12	NS	27	7	56	**
Ceratopogonoid larvae	22	59	3	19	23	**	20	14	15	11	16	NS	12	8	8	28	11	**	126	76	67	**
Oligochaeta	82	35	81	95	64	**	110	106	107	133	97	NS	88	35	103	84	99	**	357	553	409	**
Glassiphoniidae	5	6	6	10	5	NS	5	10	14	8	7	NS	3	3	5	10	7	NS	32	44	28	NS
Arachnida	3	1	2	4	1	NS	3	2	0	2	0	NS	7	2	1	1	1	NS	11	7	12	NS
Mulscus	0	0	1	0	0		0	11	1	0	1	**	0	0	2	0	1	NS	1	13	3	**
Caddis larvae	10	4	7	7	6	NS	4	7	3	3	3	NS	0	1	0	0	0	NS	34	20	1	**
Eurycercus lamellatus	7	6	5	7	0	NS	8	3	9	4	1	NS	12	8	12	5	7	NS	25	25	44	*

* = P <0.05, ** = P <0.001, χ^2-tests.

N.B. In some cases the expected numbers in the data were less than 5; these increase χ^2 value and the chance of a significant result. Since the outcome of this test was not significant, these values have not invalidated the test.

criterion was tested by using χ^2-tests on the number of individuals of the taxa across the sub-samples. A non-significant difference between the sub-samples was taken to indicate stabilization of the abundance of the taxon under consideration. This method of determining sample size was used rather than the traditional way of using the diversity measure because the latter method requires large sample size which is too laborious.

Samples were washed through a sieve (400 μ) under tap water and the invertebrates were separated by a flotation technique (Ibrahim 1988). Identifications were made according to the identification keys produced by Freshwater Biology Association.

To study variation in the invertebrate community of a given substrate, individuals of a given taxon found in the sub-samples were totalled for each month and a χ^2 - test was used to test the level of significance. The variations in the benthic communities were broadly similar above the three substrates. Therefore the data obtained from the vegetated substrate is presented here (Table 1) as a representative.

As Table 1 shows, invertebrate taxa were generally represented more or less equally (i.e. the difference was not significant) in the sub-samples within each month of sampling. In contrast, between months, a significant difference in the representation of the majority of invertebrate taxa was found. These results might indicate that the sampling method is efficient as sampling benthic community.

Advantages of the Sampling Method

1. In principle, compared to other sampling methods (eg. hand-sweeping net), this method is very accurate since all the invertebrates in the quadrate can be sampled.

2. By filling the tray with the excavated material, a large number of invertebrates is already represented in the sample. This reduces the time required for colonization.

3. The transparency of the bottom of the tray makes it inconspicuous against the background, and so avoids any interaction between the invertebrates and the tray bottom. This property can be important in the case of stony substrates, where parts of the tray bottom often remain exposed even after it has been filled with stones.

4. The mesh walls of the tray allow colonization by burrowing organisms such as Oligochaeta. This property was successfully tested in the laboratory by leaving the tray in a box (70x40x15 cm) containing sand and 100 oligochaets. Within six hours, eight individuals had passed through the mesh into the tray.

5. The tray cover helps to protect the sample, and avoids the possibility of invertebrates being lost as the tray is raised.

Disadvantages of the Sampling Method

1. It can not be operated conviently in waters deeper than c.150 cm.

2. It can not be used in very soft substrates, since the whole tray may sink.

3. It is time consuming, since it requires some weeks for full colonization.

Summary

A sampling technique to provide a quantitative estimate of invertebrate benthic fauna in standing water is described. The technique can be applied conveniently on substrates of various degrees of structural complexity, and in water depths of up to c.150 cm. The technique was used to sample benthic invertebrates from Loch Lomond and the data obtained is presented. The advantages and disadvantages of this technique are discussed.

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We would like to thank Dr. R. Tippett, Mr. R. McMath and Mr. T. Brennan for providing facilities and help with the field work at the University Field Station at Rowardennan; also Dr. R.N. Gibson and Dr. P.S. Davies for useful comments on an earlier version of this manuscript. This paper is a part of a project financed by Tishreen University, Syria.

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THE LAKE OF MENTEITH: SOME ASPECTS OF ITS ECOLOGY

By IAN FOZZARD and MARTIN MARSDEN
Forth River Purification Board

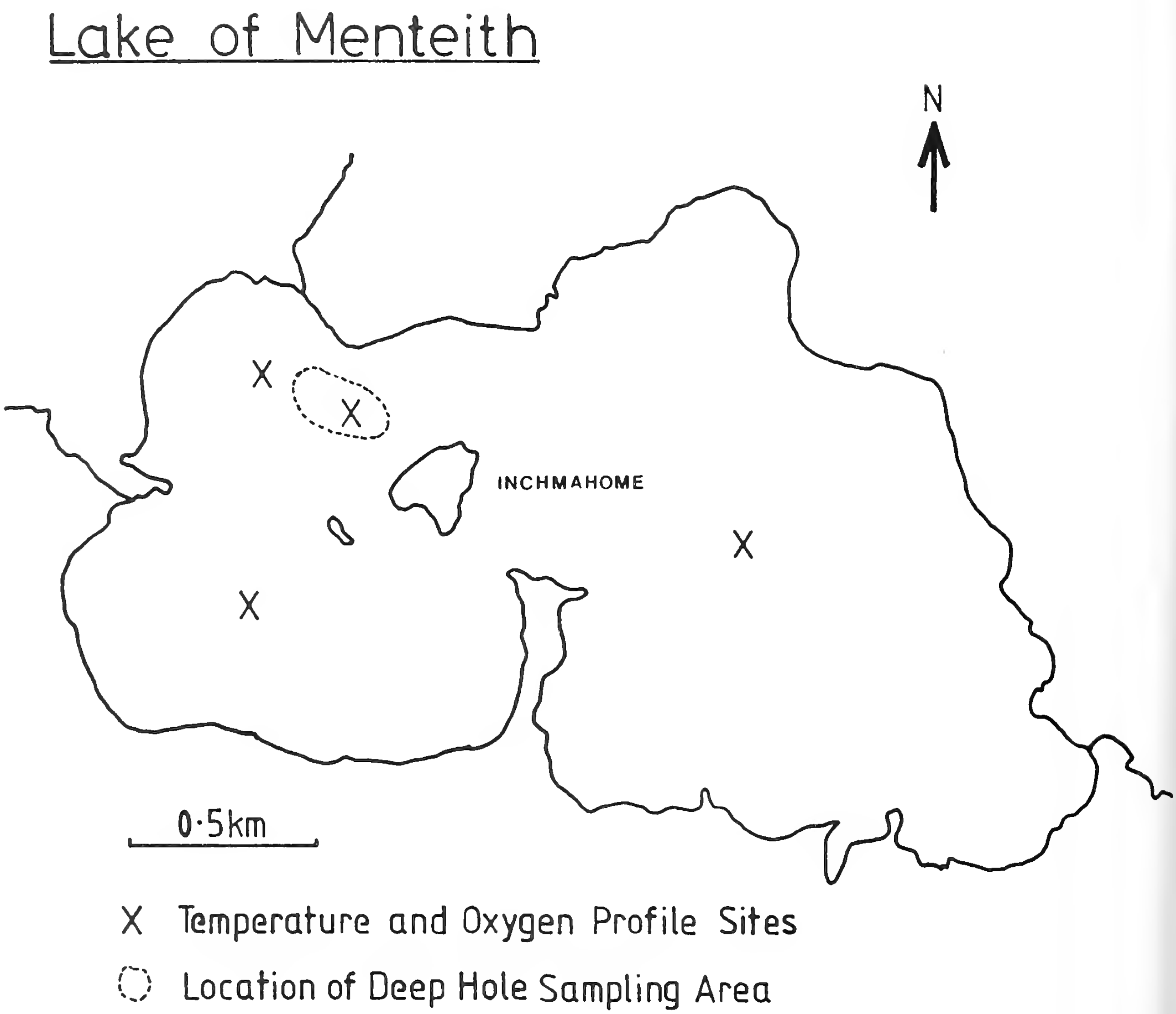
Introduction and Site Description

The Lake of Menteith (NN 580000) lies some 22 km to the west of Stirling at the western extremity of a wide lowland plain of flat carse clays and peat mosses drained by the River Forth. The lake is south of the Highland Boundary Fault and lies on superficial deposits behind a morainic belt. It is a shallow water-body with a mean depth of six metres; there is an area of much deeper water (maximum 23.5 m) to the north-west of the island of Inchmahome (Map 1), but this represents only a small proportion of the total lake volume. The lake measures approximately 2.6 km by 1.6 km, with a volume of 15.9 x 10^6 m^3 (Murray and Pullar 1910), and its mean water retention time has been calculated to be 0.8 years, based on flow gaugings on the outlet stream, the Goodie Water (Forth River Purification Board, unpublished data).

The lake is popular with tourists and casual visitors. There are picnic sites, holiday chalets, an hotel on the east shore, and an important historical site on the largest island, Inchmahome. This island attracts many visitors during the summer months, with a boat service operating from the east shore near the hotel.

In recent years, collections of '*Cladophora* balls' along the eastern shore, and algal blooms, have caused complaints from residents and visitors. The sources of nutrients which create this algal productivity are limited. There is an important fishery for Rainbow Trout *Salmo gairdneri;* in a normal year, 15 tonnes of fish are reared in ponds adjacent to the main influent stream and in cages floating in the lake. The hotel, tourist toilets on Inchmahome, and seventeen households, all have septic tanks draining eventually into the lake. Over 50% of the catchment consists of rough grazing, woodland and marsh, with the remainder being evenly split between forestry and improved grazing receiving some fertiliser application.

The manifestation of eutrophication in the Lake of Menteith led to the initiation of a survey of the lake by the Forth River Purification Board (F.R.P.B.) in 1981. This paper describes this survey and the subsequent work in 1983 and 1985.


Lake of Menteith
N
INCHMAHOME
X
X
X
X
0·5km
X Temperature and Oxygen Profile Sites
Location of Deep Hole Sampling Area

Map 1

Methods

All samples were taken over the deep hole to the north-west of the island of Inchmahome (NN 572007), unless otherwise stated.

Physical and Chemical

Surface water samples, each of one litre, were taken in April, June, August and September 1981, and in June, August and September 1985. A tube sample for nutrient and chlorophyll *a* analysis was taken through 6 m of the water column in February 1983. Dissolved oxygen and temperature profiles were taken, using a portable dissolved-oxygen meter and a submersible recording dissolved-oxygen meter in 1981, and the submersible meter alone in 1985.

Additional profiles in each of the main basins of the lake were taken during 1985. Water samples for nutrient analysis and for oxygen analysis (to check meter readings) were taken at various depths using a Casella sampler. Sediment samples were taken on each sampling date in 1981 and in June and August 1985; each sample consisted of five replicates taken by a small Van-Veen grab.

All samples were analysed in the Stirling Chemistry Laboratory of the Forth River Purification Board, using standard methods.

Plankton

In 1981 zooplankton and phytoplankton samples were taken, on the same dates as the chemical samples, using a 60 µm aperture Freshwater Biological Association standard plankton net of 24 cm mouth diameter. The net was hauled vertically through the water column from 15 m depth. Five replicate samples were taken. The samples were preserved in alcohol and stored. Mature crustacean zooplankton were identified, and notes taken on the abundant net phytoplankton.

In subsequent surveys, the methodology of sampling, sample treatment, and identification was developed considerably. The standard phytoplankton sampling method used a 15 m length of 2.0 cm internal diameter polyethylene tubing. This was lowered vertically through the water column, with the aid of a large weight, and the column of water sampled was run into a large clean polyethylene vessel. One sample was taken in February 1983, and two replicates were taken in June and in August 1985. A two litre subsample was taken from each column sample and sedimented using Lugol's iodine in measuring cylinders. After four days the top 75% of the supernatant fluid was removed by siphon and the remaining 25% added to a smaller measuring cylinder, and the process repeated. This was continued until approximately 20 ml of liquid containing the phytoplankton remained.

The 1983 phytoplankton was identified and counted by Dr. A.E. Bailey-Watts of the Institute of Terrestrial Ecology. The 1985 samples were identified to genus using Bourelly, Volumes One (1966) and Two (1968), West and Fritsch (1932), Lind and Brook (1980) and Barber and Haworth (1981). Estimates of absolute abundance were made using a Sedgwick-Rafter counting chamber, filaments and colonies being counted as one unit.

In 1983 and 1985 the zooplankton was collected, on the same days as the phytoplankton, using a specially designed zooplankton net, with a mouth diameter of 40 cm, net length of 2.0 m, aperture of 118 µm, and an open area ratio of 5:1. This net, which would theoretically give a filtering efficiency of 95%, was based on guidelines from Tranter (1968). No signs of clogging were observed, even when used in blue-green blooms. One 6.0 m vertical pull was taken in 1983 and five 15 m vertical pulls were taken on each visit in 1985.

All zooplankton samples (1981-1985) were preserved immediately in ethanol, and the crustacean zooplankton identified using Scourfield and Harding (1966) and Harding and Smith (1974). References were made to Gurney (1933) and Sars (1918) for identification of the *Cyclops strenuus* group. Counts were made using a grooved perspex block (Mr. D.H. Jones, Institute of Terrestrial Ecology, Edinburgh). The efficiency of subsampling was checked for nauplii and *Diaptomus;* the results showed agreement with the Poisson series at the 95% probability level (χ^2 test), and it was therefore assumed that the plankton was randomly sampled and a single sub-sample was used. Relative abundances were calculated for 1981, and absolute abundances for 1983 and 1985 samples. The numbers of zooplankton in the two-litre sub-sample from the phytoplankton tube were counted to provide an additional estimate of abundance, to compare with that produced by the zooplankton net sample.

Profundal benthos

Samples were taken from the sediment at the deepest part of the lake, location being checked by observation of land marks on shore. Due to the diversity of species within the sample and to seasonal variation, an optimum sample number which would efficiently sample all taxa at all seasons could not be estimated. Five sub-samples, taken by a miniature Van-Veen grab, were taken on each occasion, to collect the common species and to give some indication of their abundance and distribution. Samples were taken in April, June, August and September 1981, and June and August 1985. Samples were also taken in 1983, to obtain larval Chironomidae for rearing.

Each grab sub-sample, of 225 cm^2 area and 15 cm bite depth, was individually placed in a polythene bag, returned to the laboratory, and fixed overnight in formaldehyde. Samples were subsequently gently sieved through a 250 µm aperture brass test sieve, and were then sorted by hand in large white plastic trays measuring 30 cm x 45 cm. Each sample was sorted for approximately three hours, and the specimens removed were stored in glass tubes in a 70% ethanol with glycerol mixture.

Chironomid larvae, *Chaoborus* and Oligochaeta were slide mounted in Berlese Fluid and identified, after several week's clearing, by using the keys of Brindle (1962), Brinkhurst (1971), Pinder and Reiss (1983), and Langton (1984). The large majority of the Oligochaeta were immature specimens which could not be identified even to genus. Accordingly they were divided into two groups: 'Limnodrilus-type' without hair chaetae, and 'Tubifex-type' with hair chaetae. The key of Ellis (1962) was used to identify the *Pisidium* shells following cleaning.

Some grab samples from 1983 and 1985 were sorted live, and chironomid larvae reared to confirm identification, using the keys of Pinder (1978) and Langton (1984).

Results

Physical and Chemical

Based on the 1981 and 1985 chemical data (Table 1), the Lake of Menteith had a mean alkalinity of 22.5 mg l^{-1} and a pH between 6.5 and 7.6. The conductivity of the water ranged between 72.5 and 81.0 µs cm^{-1}, while chloride values between 6.0 and 9.0 mg l^{-1} were recorded. Problems were encountered with the analysis of nutrient concentrations, due to the limits of detection being too high. However, the relatively rich nutrient nature of the lake was illustrated, with total phosphorus concentrations reaching 80 µg l^{-1} and total oxidised nitrogen concentrations of 260 µg l^{-1} being recorded. Chlorophyll *a* varied according to the time of year, with maximum recorded concentrations of 37 µg l^{-1} in July 1981 and 13.2 µg l^{-1} in July 1985.

Thermal stratification of the whole water-body was not observed. In August 1985, temperature profiles were taken in different areas of the lake which indicated isothermal conditions except in the area of the deep hole (Figures 1, 2, 3 and 4). This thermocline was detected over the deep hole in

Table 1. Summary of Water Quality Data, Mean and Ranges.

		1981 (n=4) Surface Water	1983 Tube Sample	1985 (n=3) Surface Water
pH		7.30 (7.1-7.6)	-	6.60 (6.5-6.8)
Alkalinity (as $CaCO_3$)	(mg l^{-1})	24.40 (20.0-35.0)	-	20.00 (15.0-30.0)
Conductivity	(μs cm^{-1})	77.60 (72.5-81.0)	-	73.40 (73.0-75.0)
Chloride	(mg l^{-1})	7.30 (6.0-9.0)	-	7.00
Ammonia N (as N)	(μg l^{-1})	30.00 (10.0-50.0)	30.00	30.00 - <100.0
Total oxidised N (as N)	(μg l^{-1})	80.00 (10.0-255.0)	200.00	<100.00
Ortho P (as P)	(μg l^{-1})	<10.00 - 70.0	40.00	<10.00 - 20.0
Total P (as P)	(μg l^{-1})	80.00 - <100.0	50.00	30.00 (10.0-50.0)
SiO_2	(mg l^{-1})	0.80 (0.2-1.4)	-	0.10
Chlorophyll *a*	(μg l^{-1})	15.20 (2.6-36.9)	1.40	9.60 (6.6-13.2)
Pheopigment	(μg l^{-1})	<1.00 - 4.70	1.00	<1.00 - 2.70
Secchi disc depth	(m)	2.80 (2.0-3.5)	2.50	2.30 (2.0-2.8)

Lake of Menteith: Geographical Distribution of Thermocline

28 August 1985 (1230 - 1500hrs)

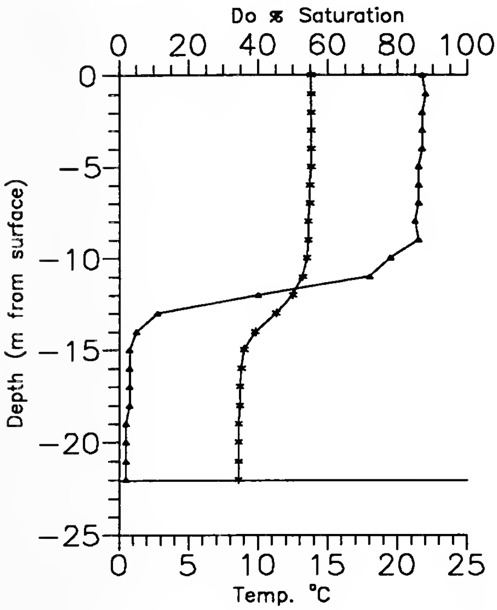


Fig 1 NW Inchmahome, 28-Aug-85

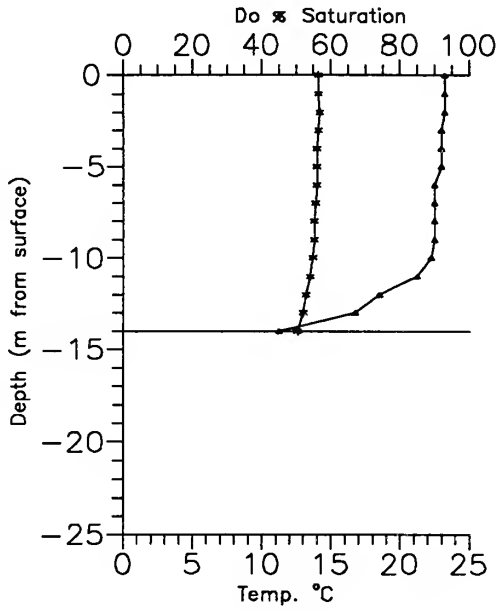


Fig 2 West of deep hole, 28-Aug-85

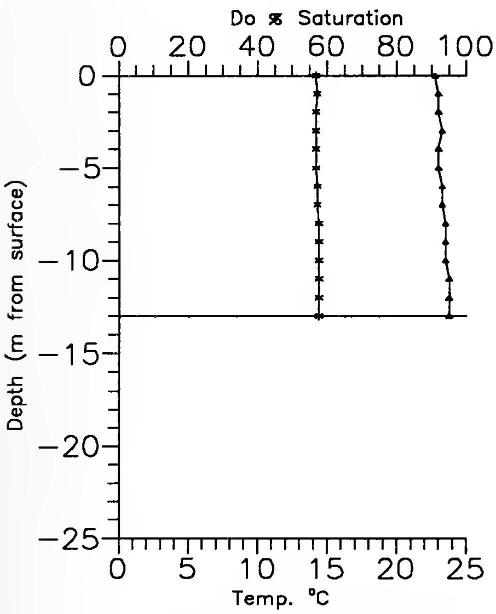


Fig 3 East of Inchmahome, 28-Aug-85

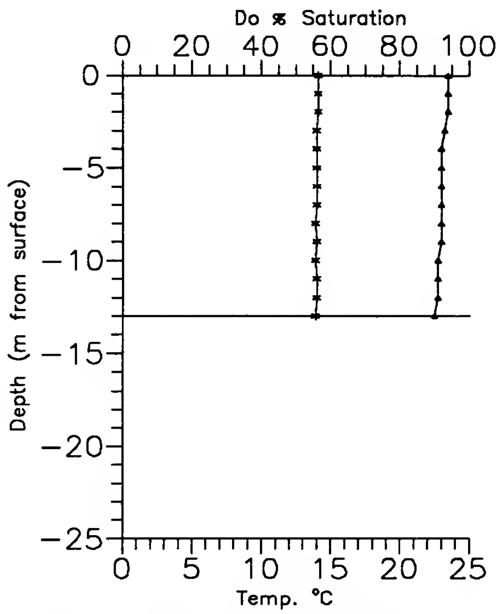


Fig 4 Centre of SW Basin, 28-Aug-85

***** Temperature: °C
▲▲▲▲▲ Dissolved Oxygen: % Saturation

Lake of Menteith: NW of Inchmahome

Seasonal Change 1981 (1200hrs)

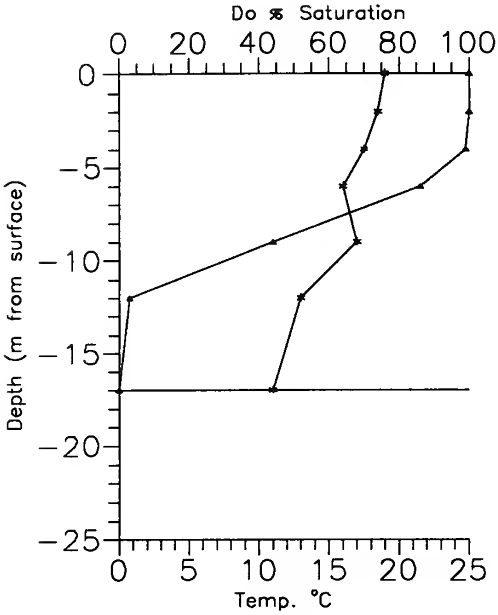


Fig 5 NW of Inchmahome, 13-Aug-81

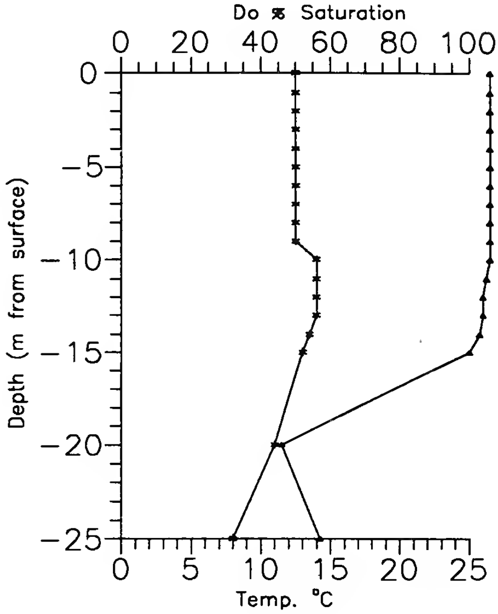
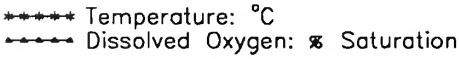


Fig 6 NW of Inchmahome, 24-Sep-81



Lake of Menteith: NW of Inchmahome

Seasonal Change 1985 (1200 - 1300hrs)

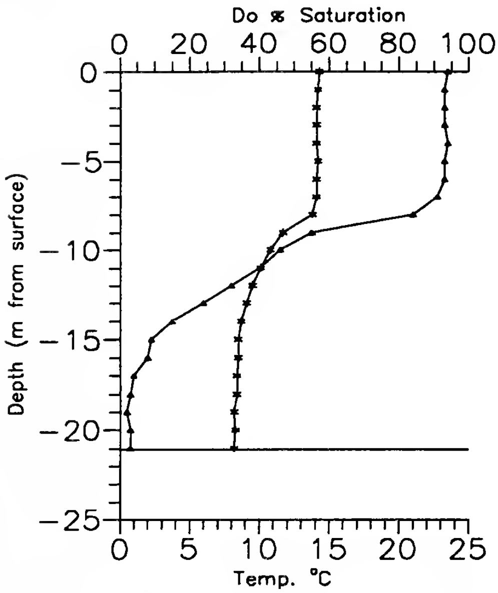


Fig 7 NW of Inchmahome, 27-Jun-85

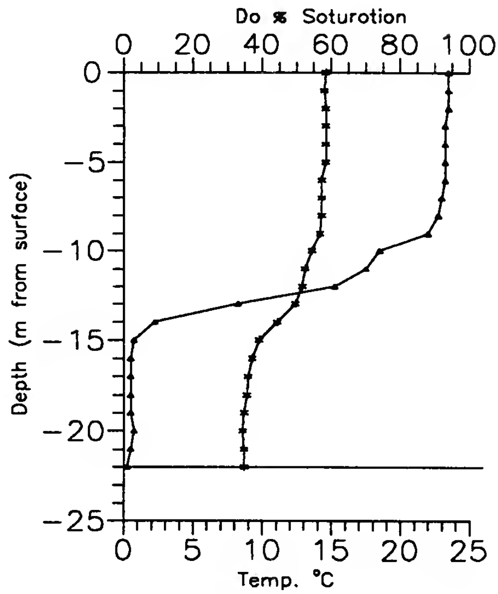


Fig 8 NW of Inchmohome, 21-Aug-85

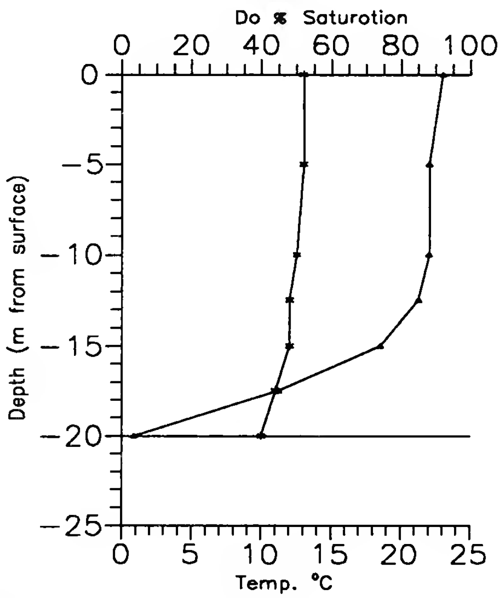


Fig 9 NW of Inchmohome, 26-Sep-85

Temperature: °C
Dissolved Oxygen: % Saturation

Table 2. Comparison of Water Quality at the Surface and at the Bottom of the Deep hole (approx. 20 m depth, 1 m above mud surface) during Stratification in 1985.

SAMPLING DATE		27.06.85		21.08.85		26.09.85	
		Surface	Bottom	Surface	Bottom	Surface	Bottom
Dissolved oxygen	(%ge)	94.0	3.0	94.0	1.0	92.0	4.0
Ammonia N (as N)	($\mu g\ l^{-1}$)	30.0	440.0	40.0	970.0	<100.0	500.0
Ortho P (as P)	($\mu g\ l^{-1}$)	<10.0	90.0	10.0	210.0	20.0	470.0
Total P (as P)	($\mu g\ l^{-1}$)	10.0	130.0	40.0	260.0	50.0	510.0

1981 and 1985 at a depth of 8.0 m early in the year, deepening to 12.0 m by late summer. Deoxygenation of the hypolimnion was observed in 1981 and 1985, with the percentage oxygen saturation of the water falling to less than 5% (Figures 5 and 6). Measurements of the oxygen profile in 1985 revealed that deoxygenation occurred rapidly during the early summer (Figures 7, 8 and 9).

The stratification was observed to break up during September in both 1981 and 1985. Chemical measurements of the water within the hypolimnion (Table 2) suggested that concentrations of ammonia, orthophosphate and total phosphorus in the deoxygenated zone increased during the summer, until by September the concentrations were an order of magnitude greater than those in the surface waters.

Analysis of sediment from the bottom of the deep hole indicated that percentage loss on ignition (a measure of the organic content) varied between 19.0% and 27.9%, and that total phosphorus content varied between 0.3 g kg^{-1} and 2.3 g kg^{-1}. Overall, the levels of total phosphorus and the percentage loss on ignition were higher in 1985 than in 1981 (Table 3).

Phytoplankton

Blue-green algae and diatoms were usually the most important groups present. In the 1981 net samples (Table 4) the blue-green algae *Anabaena*, *Gomphosphaeria* and *Microcystis*, and the diatoms *Asterionella* and *Fragilaria* were always recorded. The sample taken on 8th February 1983 (Table 5) was dominated by the blue-green alga *Aphanizomenon* along with centric diatoms (especially *Melosira*). Chrysophytes (1000 cells ml^{-1}) were common in June 1985 (Table 6), but *Anabaena* was also present (17 filaments ml^{-1}). The August 1985 samples showed a reduction in the chrysophyte population to 9.0 cells ml^{-1}, while *Aphanizomenon* was the most numerous plankter with 93 filaments ml^{-1}. Diatoms (*Melosira*, *Tabellaria* and *Fragilaria*), *Ceratium* and *Coelosphaerium* were present in large numbers.

Algal blooms have been recorded regularly in the Lake of Menteith and have been the subject of several compaints. The following blooms have been recorded from recent years:

(a) 8th August 1984, *Gomphosphaeria* and *Anabaena*, water bright green along east shore, and

(b) 26th September 1985, *Aphanizomenon* bloom, concentration of 610 filaments ml^{-1} at the surface along the east shore.

Table 3. Summary of Sediment Analyses, 1981 and 1985.

SAMPLING DATE	April 1981	June 1981	Aug 1981	Sept 1981	1981 Annual Means	Range of Individual Values
	n=4	n=4	n=5	n=5	n=18	n=18
Mean Percentage loss on ignition*	21.60%	20.25%	21.69%	20.24%	20.30%	19.00 - 24.00
Mean Total P g/kg**	0.70	0.70	0.53	1.08	0.75	0.03 - 2.05

SAMPLING DATE	June 1985	Aug 1985	1985 Annual Means	Range of Individual Values
	n=5	n=5	n=10	n=10
Mean Percentage loss on ignition*	27.06%	23.52%	25.29%	21.30 - 27.90
Mean Total P g/kg**	1.85	1.30	1.58	1.16 - 2.30

* Percentage loss on ignition is calculated as loss on ignition at 500°C from sediment dried at 105°C.

** Total P is calculated as g of P per kg dry weight of sediment dried at 105°C.

Table 4. Common Phytoplankton, 1981.

Species	24 June	09 July	13 Aug	24 Sept
Anabaena	+	+	+	+
Microcystis	+	+	+	Abundant
Gomphosphaeria	+	+	+	+
Ceratium	+	+	+	+
Gloeotrichia	-	-	-	+
Asterionella	+	+	+	+
Fragilaria	+	+	+	+
Mallomonas	+	+	+	+
Ulothrix	-	+	-	-
Cosmocladium	-	-	+	-
Melosira	-	-	-	+
Micrasterias	-	-	-	+

Table 5. Phytoplankton. Absolute Abundance, 1983.

	8 February
	Number per ml
MYXOPHYTA	
Coelosphaerium kuetzingonum (Nag)	0.25
Gomphosphaeria lacustris Chod.	0.50
Anabaena flos-aquae Breb *ex* Born *et* Flah. f. *flos-aquae* (Komarek)	0.25
Anabaena spiroides Klebahn	0.25
Pseudanabaena	0.50
Aphanizomenon flos-aquae (Ralfs *ex* Born. *et* Flah.)	145.57
CRYPTOPHYTA	
Rhodomonas minuta Skuja or *R. lacustris* Pasch *et* Ruthner	24.40
Cryptomonas Ehrenb.	3.76
PYRRHOPHYTA	
Gymnodinium helveticum Penard var. *achroum* Skuja	0.25
CHRYSOPHYTA	
Chrysoflagellates	5.64
BACILLARIOPHYTA	
Melosira italica (Ehr.) Kutz prob. subsp. *subarctica* O. Mull	25.50
Melosira granulata (Ehr.) Ralfs	27.35
Unicellular centric diatoms prob. *Stephanodiscus* Ehr. *Cyclotella* Kutz types	16.92
Asterionella Hass.	0.98
Tabellaria fenestrata (Lyngb.) Kutz	R
Fragilaria Lyngb.	R
CHLOROPHYTA	
Dictyosphaerium pulchellum Wood	0.25
Closterium (prob. *limneticum* Lemm group)	R
Ankistrodesmus prob. *contorta*	R

R = rare.

Table 6. Phytoplankton. Absolute Abundance, 1985.

	*25 June	*28 August
		Number per ml
MYXOPHYTA		
Coelosphaerium } *Gomphosphaeria* }	2.6	7.2
Anabaena	15.8	7.6
Aphanizomenon	1.3	77.5
Oscillatoria	P	-
CRYPTOPHYTA		
Rhodomonas	9.5	44.0
Cryptomonas	9.5	12.5
PYRRHOPHYTA		
Ceratium	1.8	6.7
CHRYSOPHYTA		
Dinobryon	2.0	0.2
Mallomonas	2.7	2.0
Chrysoflagellates	965.0	8.9
BACILLARIOPHYTA		
Melosira	1.6	3.2
Stephanodiscus?	P	P
Asterionella	0.2	0.2
Tabellaria	0.9	6.6
Fragilaria	0.8	3.7
CHLOROPHYTA		
Chloroflagellates	P	P
Colonial Chlorococcales } (i.e. *Dictyosphaerium*, *Coenochloris*?) } *Kirchneriella*, *Ankistrodesmus* }	2.5	3.3
Colonial Volvoccales (i.e. *Pandorina*, *Volvulina*, *Volvox*)	P	P
CONJUGATOPHYTA		
Closterium	-	P
Cosmarium	0.6	10.9
Staurastrum	P	-
Mougeotia	P	P
Spirogyra	P	-

* Mean of two tube samples

P = present, but no accurate figures

\- = not recorded

Zooplankton

The crustacean zooplankton was dominated by two genera, *Diaptomus gracilis* and *Daphnia* spp. (Tables 7 and 8). They represented between 81% and 99% of the crustacean zooplankton.

There were two species of *Daphnia* present: *D. hyalina* dominated in spring, while *D. obtusa* became more important over the summer. In September 1981, *D. obtusa* represented 53% of the *Daphnia* spp. present. The winter sample, taken in February 1983, was noticeably different from the others (Table 8). It had a low species diversity with *Diaptomus gracilis* dominating, representing 95% of the crustacean zooplankton.

High densities of crustacean zooplankton were found on all sampling occasions, with up to 17 individuals per litre, excluding nauplii.

Profundal Benthos

The Oligochaeta were the numerically dominant taxa in the lake profundal benthos in both 1981 and 1985, forming up to 96% of the fauna (Table 9). Immature tubificids with hair chaetae ('Tubifex-type') usually represented over 95% of all oligochaetes (Table 9). *Tubifex tubifex* was identified in 1985 and *Limnodrilus hoffmeisteri* in 1981. The 'Tubifex-type' Oligochaeta were most in abundant in the August samples. Since the Oligochaeta appeared to be distributed in scattered groups on the lake bottom, an estimation of the population mean could not be made with the small number of samples available (see Elliott 1977), but the value is likely to lie in the range of several thousand per square metre.

The chironomids were most abundant in the spring/early summer, while low numbers were found in the August and September samples. The most common larvae were *Sergentia*, *Tanytarsus*, and *Chironomus*. *C. anthracinus* was successfully reared from samples taken during 1983. *Sergentia* has not been reared to date, but only one species, *S. coracina*, has been recorded for the British Isles. *Tanytarsus* has also proved difficult to maintain in the laboratory and has not been reared to date. The *Tanytarsus* larvae from the samples were all very similar and may all belong to the same species, although there are some 29 species listed in the British checklist of Kloet and Hincks (1976).

Despite being randomly distributed on the lake bottom, the density of chironomids in the profundal sediments could not be calculated with any precision due to the small number of samples and low number of individuals in the samples, but was probably a few hundred per m^2. For example, the population mean

Table 7. Zooplankton. Percentage Abundance, 1981.

	30 April	24 June	09 July	13 Aug	24 Sept
Daphnia hyalina Leydig	39	36	40	22	21
D. obtusa Kurz	-	5	15	19	23
Ceriodaphnia	-	<1	-	-	P
Diaphanosoma brachyurum (Lieven)	-	9	4	9	17
Bosmina } *B. coregoni* Baird	1	-	-	-	-
Alona intermedia (Sars.)	<1	-	-	-	-
Leptodora kindti (Focke)	-	4	1	-	-
Diaptomus gracilis (Sars.)	56	42	38	48	34
Cyclops	4	} 4	2	2	5
C. strenuus Fischer	-	}			
C. gigas (Claus)	-	-	P	-	-
Nauplii	P	P	P	P	P
Chaoborus	-	P	P	P	P

P = present, but no accurate figures.

\- = not recorded.

Table 8. Zooplankton. Absolute Abundance, in numbers per litre, 1983 and 1985.

	08 Feb Net	1983 Tube	28 June *Net	1985 Tube	28 Aug *Net	1985 Tube
Daphnia hyalina Leydig	0.20	0.60	6.30	9.30	3.60	5.25
D. obtusa Kurz	-	-	0.10	0.20	1.20	1.75
Ceriodaphnia quadrangula (Muller) S.str.	-	-	0.10	-	P	-
Diaphanosoma brachyurum Lieven	-	-	0.20	0.50	2.40	2.75
Bosmina coregoni Baird	0.04	-	0.004	-	-	-
Leptodora kindti (Focke)	-	-	0.40	-	0.03	-
Diaptomus gracilis (Sars)	5.00	4.00	6.40	7.50	6.60	6.50
Cyclops	0.03	-	0.08	-	0.30	0.75
Chaoborus	-	-	0.05	-	0.09	-

* mean of five trawls.

P = present, but no accurate figures.

\- = not recorded.

Table 9. Profundal Benthos. Mean Number per Grab, 1981 and 1985.

	1981				1985	
	*30 April	25 June	13 Aug	24 Sept	25 June	21 Aug
NEMATODA indeterminate	-	-	1	-	-	-
OLIGOCHAETA						
Oligochaete egg capsules	30	35	42	113	36	Common
Naididae indeterminate	-	-	-	-	1	1
Stylaria lacustris (Linn.)	-	-	-	-	1	-
Tubifex-type (immature)	140	58	300	125	102	495
Tubifex tubifex (Muller)	-	-	-	-	1	4
Limnodrilus-type (immature)	-	-	-	-	2	2
Limnodrilus hoffmeisteri Claparede	3	2	22	-	-	-
Enchytraeidae	-	-	-	-	-	1
SPHAERIIDAE						
Pisidium casertanum (Poli)	2	5	7	2	6	2
CHIRONOMIDAE						
Chironomidae indeterminate	2	-	-	-	-	-
Tanytarsus sp. v.d. Wulp	-	4	1	-	25	-
Sergentia (*coracina*) Keiffer	15	5	2	-	32	-
Chironomus (*anthracinus*) Meigen	8	4	8	2	9	7
Endochironomus Kieffer	1	-	-	-	-	-
Procladius Skuse	1	-	-	-	-	-
CULICIDAE						
Chaoborus flavicans Meigen	104	15	2	13	104	2
Chaoborus pupae	-	-	-	-	13	-

* Mean of six grabs; other dates mean of five grabs.

- = not recorded.

for *Chironomus* on 25th June 1985 probably (P = 0.95) lay between 40 and 280 m^2, and for *Sergentia* probably (P = 0.95) lay between 164 and 348 per m^2 (Elliott 1977).

Chaoborus flavicans was present in similar numbers in the 1981 and 1985 samples, but the occurrence of these larvae in the grab samples diminished in August. *Pisidium casertanum* was present in low numbers in all samples taken from the profundal benthos.

Discussion

Historical

The Lake of Menteith was visited by Murray and Pullar (1910), during the Bathymetric Survey of Scotland. They produced a description of the morphometry of the lake and an analysis of its sediment. A spot chemical sample was taken by Mr. J.D. Hamilton (Paisley College of Technology) in 1955 (Table 10). In 1970-1971 Mr. Brian Morrison (Freshwater Fisheries Laboratory) took chemical samples of the lake, measured oxygen profiles, and carried out zooplankton trawls (unpublished data).

Maulood and Boney (1981) published the results of a chemical and phytoplankton sampling programme of the Lake of Menteith in 1972-1973. A survey of the aquatic macrophytes and zooplankton of the Trossachs lochs was carried out by the Nature Conservancy Council in 1981, and this included a single zooplankton trawl in the Lake of Menteith (N.C.C., unpublished data).

Physical and Chemical

The limited number of measurements taken during the period 1981 to 1985 restrict interpretation to a general comparison with previous results.

The pH of the lake has been consistently reported as about neutral. Hamilton (pers. comm.) measured a pH of 6.8 in September 1955. Maulood and Boney (1981) reported a pH minimum of 7.0 during December 1972, rising to a maximum pH of 7.7 in August 1973. They suggested that this increase in pH was associated with photosynthesis. During 1981, pH values displayed a similar range between 7.1 and 7.6, and the variation was parallelled by chlorophyll *a* concentrations. In 1985 the pH values were lower, between 6.5 and 6.8. This difference was probably due to higher rainfall, and lower photosynthetic activity, during the wet summer. The alkalinity of the lake was recorded as 19.6 mg l^{-1} in September 1955 and 25.5 mg l^{-1} in 1972/73 (Maulood and Boney 1981). This compares

Table 10. Surface Water Sample taken by Mr. J.D. Hamilton on 14th September 1955.

pH		6.84
Alkalinity (as $CaCO_3$)	(mg l^{-1})	19.60
Calcium	(mg l^{-1})	20.80
Magnesium	(mg l^{-1})	7.10
SiO_2	(mg l^{-1})	1.03
Total P	(µg l^{-1})	7.00
Sodium	(mg l^{-1})	4.50
Potassium	(mg l^{-1})	0.50
Chloride	(mg l^{-1})	8.30

well with the 1981/85 data (range 15-35 mg l^{-1}). The slightly lower values for 1985 compared with 1981 are again probably related to higher rainfall during the summer.

Orthophosphate concentrations recorded by Maulood and Boney (1981) for 1972/73 ranged between a winter maximum of 6.0 $\mu g\ l^{-1}$ and a summer minimum of 2.0 $\mu g\ l^{-1}$. These values appear to be low in comparison with our data from other lochs within the Forth catchment. In Menteith during 1981 and 1985, orthophosphate levels ranged between <10 and 70 $\mu g\ l^{-1}$, (10 $\mu g\ l^{-1}$ being the lower limit of analytical detection). Total phosphorus concentrations measured by the F.R.P.B. in 1981 and 1985 were in the meso/eutrophic range quoted by the Organisation for Economic Cooperation and Development (Anon 1982). Nitrate levels during 1972/73 varied between a winter maximum of 210 $\mu g\ l^{-1}$ and a summer minimum of 29 $\mu g\ l^{-1}$ (Maulood and Boney 1981). These data show agreement with our own data for Total Oxidised Nitrogen (mainly nitrate) of 250 $\mu g\ l^{-1}$ maximum in spring 1981 and 10 $\mu g\ l^{-1}$ minimum in summer 1981. Within the limitations of the data, it therefore appears that nitrate levels are generally low in the summer.

Maximum Chlorophyll *a* values in the Lake of Menteith lie in the middle of the range of values quoted for eutrophic waters by the O.E.C.D. (Anon 1982). In a survey of 81 British waters of widely differing algal productivity (Collingwood 1977) it was concluded that eutrophic waters have an annual maximum chlorophyll *a* value of over 30 $\mu g\ l^{-1}$. This compares with a 1981 measured maximum for Lake of Menteith of 36.9 $\mu g\ l^{-1}$. In a local context, the measured chlorophyll *a* maximum in Menteith was much higher than in other Trossachs lochs, e.g. Loch Lubnaig 4.8 $\mu g\ l^{-1}$, Loch Ard 1.2 $\mu g\ l^{-1}$ and Loch Achray 1.9 $\mu g\ l^{-1}$ (F.R.P.B., unpublished data for 1981). In our three 1985 samples, chlorophyll *a* levels in Lake of Menteith reached 13.2 $\mu g\ l^{-1}$. This low June figure was thought to be due to increased flushing and possibly increased turbidity during the wet summer.

The Secchi disc depths, ranging between 2.0 and 3.5 m, with a mean of around 2.5 m, also lie in the middle of the range of values quoted for eutrophic waters by O.E.C.D. (Anon 1982). During the August and September 1985 surveys the water of the lake had a more distinct brown colouration, which must have contributed to light attenuation and would have compensated the lower chlorophyll *a* values recorded for this period. It was probably due to this colouration that there was little difference in Secchi disc depths between 1981 and 1985.

A notable seasonal change identified during the 1981 and 1985 survey was the deoxygenation of the hypolimnion in the deep hole. Morrison (pers. comm.) indicated that progressive deoxygenation of the hypolimnion was observed in the summers of 1970 and 1971. These data imply that the deoxygenation of the deep hole has been a regular feature of the Lake of Menteith. The morphometry of the deep hole with its relatively small volume (2.5% of lake total) is an important factor, along with the productivity of the lake, in determining its deoxygenation.

In the deoxygenated zone, total phosphorus concentrations of up to 510 $\mu g\ l^{-1}$ were recorded in September 1985. However, the small volume of the deoxygenated zone means that phosphorus levels in the whole lake would only be raised by 10 $\mu g\ l^{-1}$ if total mixing occurred. This release would be an annual event occurring at autumn mixing. Therefore the nutrients released during deoxygenation in the deep hole are probably of limited significance in relation to the lake.

Murray and Pullar (1910) quote a range of loss of ignition for the profundal sediments of the Trossachs lochs of 13-26%. More recent records for 1981 give figures of 14.9% for Loch Lubnaig, 16.9% for Loch Achray and 12.7% for Loch Ard (F.R.P.B., unpublished data). Lake of Menteith, with a range of 19-27%, has a relatively high organic content in its profundal muds. The absence of any large influent stream carrying mineral particles into the deep hole, together with the higher standing crops of phytoplankton recorded in the lake, was probably responsible for this result. Total P concentrations in the sediment of Menteith were similar to those recorded from other Trossachs lochs (F.R.P.B., unpublished data).

Phytoplankton

The phytoplankton is the component of the lentic community most responsive to changes in nutrient status. Numerous case studies have related change in water quality to the species composition of the phytoplankton (Palmer 1969, Reynolds 1984, Shapiro 1984).

Data on the phytoplankton of the Lake of Menteith are given by Maulood and Boney (1981). They sampled fortnightly between October 1972 and September 1973, and described the lake as blue-green or blue-green/diatom in nature. During winter, blue-green algae (*Anabaena* and *Coelosphaerium*) were dominant; by spring, a moderate diatom bloom developed (mainly *Melosira*, but including *Cyclotella* and *Asterionella*), which along with *Anabaena* continued through to August; after this, *Ceratium* and *Microcystis* became important.

The F.R.P.B.'s phytoplankton results are similar to those of Maulood and Boney (1981). In 1981 the plankton was dominated by blue-greens and diatoms. In the 1983 sample, *Aphanizomenon* dominated instead of *Anabaena*, with diatoms the second most important group. The blue-green algae and diatoms remained predominant in the other samples taken in 1985. However, in other respects the wet summer of 1985 produced some differences. In June a large nannoplankton population developed; *Microcystis* was not recorded, although it was common in 1973 and 1981; and *Dinobryon* was present in June and August, although this species was specifically mentioned as absent by Maulood and Boney (1981). *Dinobryon* is associated with oligotrophic conditions (Provasoli 1969, Lund 1965, Hutchinson 1967) and is said to be inhibited by high nutrient concentrations (Rodhe 1948, Holmgren 1984). Blue-green algae are important in Lake of Menteith, both in terms of abundance and species diversity. Maulood and Boney (1981) found more blue-green species in Menteith than in Loch Lomond, Loch Ard or Loch Achray (Maulood and Boney 1980, 1981, 1982).

Our own surveys have found more species of blue-greens in Menteith than in Ard, Achray, Lubnaig or Voil (F.R.P.B., unpublished data) and blue-green algal blooms were often observed. Increased importance of blue-green algae as eutrophication develops has been reported by several authors (Nilssen 1978, Bailey-Watts 1978, Moss, Wetzel and Lauff 1980). In particular, blooms of *Anabaena*, *Aphanizomenon* and *Microcystis* are typical of eutrophic lakes (Hutchinson 1967). Hutchinson classified phytoplankton communities into twelve associations. Association eleven is found in the more productive lakes of the temperate region in summer, and is characterised by the latter three genera.

The spring diatom flora described by Maulood and Boney (1981) resembles the vernal mesotrophic assemblage described by Reynolds (1980). Spring diatom blooms have been described from a wide variety of lake types (Lund 1981), but the continued importance of diatoms over the summer is more unusual, and is probably related to the absence of stable stratification (Reynolds 1980).

Desmid rich plankton has been correlated with water of low ionic concentration, often in areas of ancient igneous rock (West and West 1909). This concept has been used as the basis of several trophic indices, of which the most frequently encountered is that of Nygaard (1949). Nygaard's compound index is calculated by totalling the number of species of Myxophyceae, Chlorococcales, Centrales and Euglenophyta, and then dividing by the number of species of Desmideae. Hutchinson (1967) recommends that the index should only be used for summer plankton. Calculated for genera on the basis of the two summer

1985 samples, Lake of Menteith scores five and seven. Nygaard classifies an index above three as definitely eutrophic. Coesel (1983) criticised the Nygaard index on the basis that desmids have a wider trophic tolerance than Nygaard implies, and that the desmid pseudoplankton is frequently important. Coesel lists three desmid genera commonly found in nutrient rich water. These were the only desmids found in Lake of Menteith in 1985. Overall, a eutrophic classification of the Lake of Menteith would appear to be justified on the basis of its phytoplankton composition and abundance.

Zooplankton

There is no evidence that nutrient enrichment can directly modify the zooplankton community structure of a lake, but it may influence it indirectly (Ravera 1980). In particular, there is the shift in species composition of the phytoplankton from small edible forms to the predominance of large algae which have little food value for most zooplankters (Nilssen 1978).

The results of our 1981 and 1985 surveys are remarkably similar to those by the Nature Conservancy Council (unpublished report) and Morrison (pers. comm.). It seems that *Diaptomus* and *Daphnia* have predominated during this period. *Diaptomus gracilis* and *Daphnia hyalina* have a cosmopolitan distribution and are found over a wide trophic range (Jones 1984). They were recorded as common throughout the mainland of Scotland by Murray (1905), and as very important components of the zooplankton in surveys by Gurney (1923) in the Lake District, by Thomas (1961) in North Wales, and by Maitland, Smith and Dennis (1981) in Scotland.

Ceriodaphnia quadrangula was found in Lake of Menteith in 1981 and 1985. It is described by Jones (1984) as having a preference for mesotrophic/eutrophic waters. Makrushin (1976) describes it as an indicator of eutrophy. Scourfield and Harding (1966) state that this cladoceran occurs in ponds and lakes rich in phytoplankton. It was not found in any of the other Trossachs lochs (Lubnaig, Ard, Achray and Voil) surveyed in 1981 by the F.R.P.B. (unpublished data).

Daphnia obtusa was found in water-bodies with a wide range of water chemistry during a survey of Yorkshire by Fryer (1985). It was found predominantly in small water-bodies, and only three open water records exist. Jones (1985) found *D. obtusa* in a few lochs in Tayside, and described it as having a preference for eutrophic conditions. The only other record for the Forth catchment is for the Loch Ore Meadows Nature Reserve Ponds in Fife (F.R.P.B., unpublished data). This apparently uncommon species in Scotland, which is usually limited to small water-bodies, is an unexpected occurrence in the plankton of Lake of Menteith.

The relative abundance of the dominant zooplankton of a water-body is related to its trophic status (Jones 1984). The more eutrophic a lake, the greater the population density of cyclopoid copepods relative to that of the calanoid copepods (Petalas 1972, Jones 1984). *Diaptomus* is thought to be more suited to oligotrophic waters than eutrophic waters, due to its high filtering capacity and high ingestion rate at low densities of small algae (Ravera 1980). Therefore the high relative abundance of *D. gracilis*, and the low numbers of *Cyclops*, in the Lake of Menteith indicate that the lake still retains some oligotrophic characteristics.

Profundal Benthos

The profundal benthos is the assemblage of animals living on a lake bottom, below the compensation depth and away from any littoral influence. Some of the species which make up the profundal benthos may well be found in other habitats, but their varying ability to tolerate the particular conditions on a lake bed results in a relationship between the trophic state of the lake and the species present.

The composition of the profundal fauna is influenced by the 'rain' of plankton and allochthonous organic material it receives from the overlying water. The main controlling factors are thought to be the abundance and type of food input, the oxygen supply at the mud surface, and the temperature regime (Brundin 1949, 1956, 1958, 1974; Mundie 1957; Saether 1975, 1979; Wiederholm 1974, 1976, 1980.

There are no previous data available on the profundal benthos of Lake of Menteith. The 1981 and 1985 surveys of Menteith did not show any major differences in composition of the community, and both showed similar trends between June and August (i.e. reduction of chironomid species, persistence of *Chironomus*, and increase of 'Tubifex-type' tubificids).

The use of the Oligochaeta as indicators of trophic status was restricted by the vary low numbers of mature identifiable specimens taken in the samples. The relationship between lake type and the Oligochaeta has been reviewed by Brinkhurst (1974), Wiederholm (1974), and Milbrink (1972, 1973, 1978).

Only two species identifications of Tubificidae were made in this survey; *Limnodrilus hoffmeisteri*, the presence of which is said to be a reliable indication of eutrophic conditions, and *Tubifex tubifex*, which appears to be distributed throughout the whole spectrum of lake types and not to be usefully linked to any trophic state. The relative abundance of the Oligochaeta compared to other benthos appears to be related to trophic status, the higher the proportion of Oligochaeta the more productive the water-body. On this basis the Lake of Menteith would be classified as productive.

Schemes of lake classification using profundal chironomids were originally devised by Thienemann, and were developed by Lundbeck and Brundin in Europe (see Brinkhurst 1974) and more recently by Saether in North America (Saether 1975, 1979).

Species of *Chironomus* are well adapted to a particle rich, low oxygen habitat. *C. anthracinus* is a deposit feeder utilising recently deposited superficial sediments (Jonasson 1972); its body fluid contains haemoglobin and it is able to maintain feeding activity at low dissolved oxygen levels. *C. anthracinus* is usually considered to typify the profundal of moderately eutrophic lakes (e.g. Brundin 1956), whereas *Sergentia* is strongly associated with mesotrophic lakes (eg. Wiederholm 1974).

Large numbers of *Chaoborus flavicans* were taken in the spring and early summer grab samples from the Lake of Menteith. *Chaoborus* spp. are part planktonic, and it is possible that increasing numbers of larvae moved out of the deep hole during the period of most severe deoxygenation in August. *Chaoborus* spp. have been taken only as single specimens in grab samples from other Trossachs lochs (Achray, Ard, Lubnaig and Voil) sampled by the F.R.P.B. (unpublished data). Several authors have associated increased populations of *Chaoborus* with high productivity (Jones 1980; Smith, Cuttle and Maitland 1981).

From the available data, therefore, it appears that, during each summer, changes occurred in the composition of the fauna commensurate with the progressive deoxygenation of the hypolimnion of the deep hole.

Summary

The morphometry of the Lake of Menteith predisposes it towards eutrophic conditions. In shallow well-mixed lakes algal productivity relative to nutrient levels is maximised, since cells are maintained within the photic zone (Riley and Prepas 1985). Also recycling of nutrients between the sediments and the water column is enhanced by turbulence in shallow lakes (Ryding 1985).

Based on O.E.C.D. criteria (Anon 1982) the total phosphorus concentrations in the Lake of Menteith ranged around the mesotrophic/eutrophic level. Chlorophyll concentrations reached the mid-eutrophic range, and the phytoplankton was also

classified as eutrophic, based on its blue-green/diatom domination. The zooplankton had several representatives of species normally found under eutrophic conditions (e.g. *Ceriodaphnia quadrangula*); however, its dominance by the copepod *Diaptomus gracilis* was more typical of oligotrophic/mesotrophic conditions.

Eutrophic lakes typically experience the problem of deoxygenation of their hypolimnia. This has been demonstrated to occur in the Lake of Menteith over the whole summer. High organic input to the hypolimnion, mostly phytoplankton, is the prime factor determining this; however, the small volume of the hypolimnion and the consequently limited oxygen reserve allows this process to occur rapidly. Summer oxygen depletion of the hypolimnion in Menteith is probably a regular occurrence but not significant in the overall ecology of the lake.

The period of anoxia is probably the major factor determining the composition of the profundal zoobenthos. The fauna was dominated by species tolerant of low oxygen levels (*Tubifex* sp., *Limnodrilus* sp., and *Chironomus* sp.), along with *Chaoborus* which is capable of migrating into oxygen rich water. The fauna, however, is not limited to 'eutrophic species', and *Sergentia*, which is typical of mesotrophic lakes, was present in the spring and early summer.

The Lake of Menteith is clearly a nutrient rich lake, whose fauna display many eutrophic characteristics. It does retain, however, species typical of less enriched water-bodies. The resultant high species diversity will be a useful reference against which to gauge any change in its condition.

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