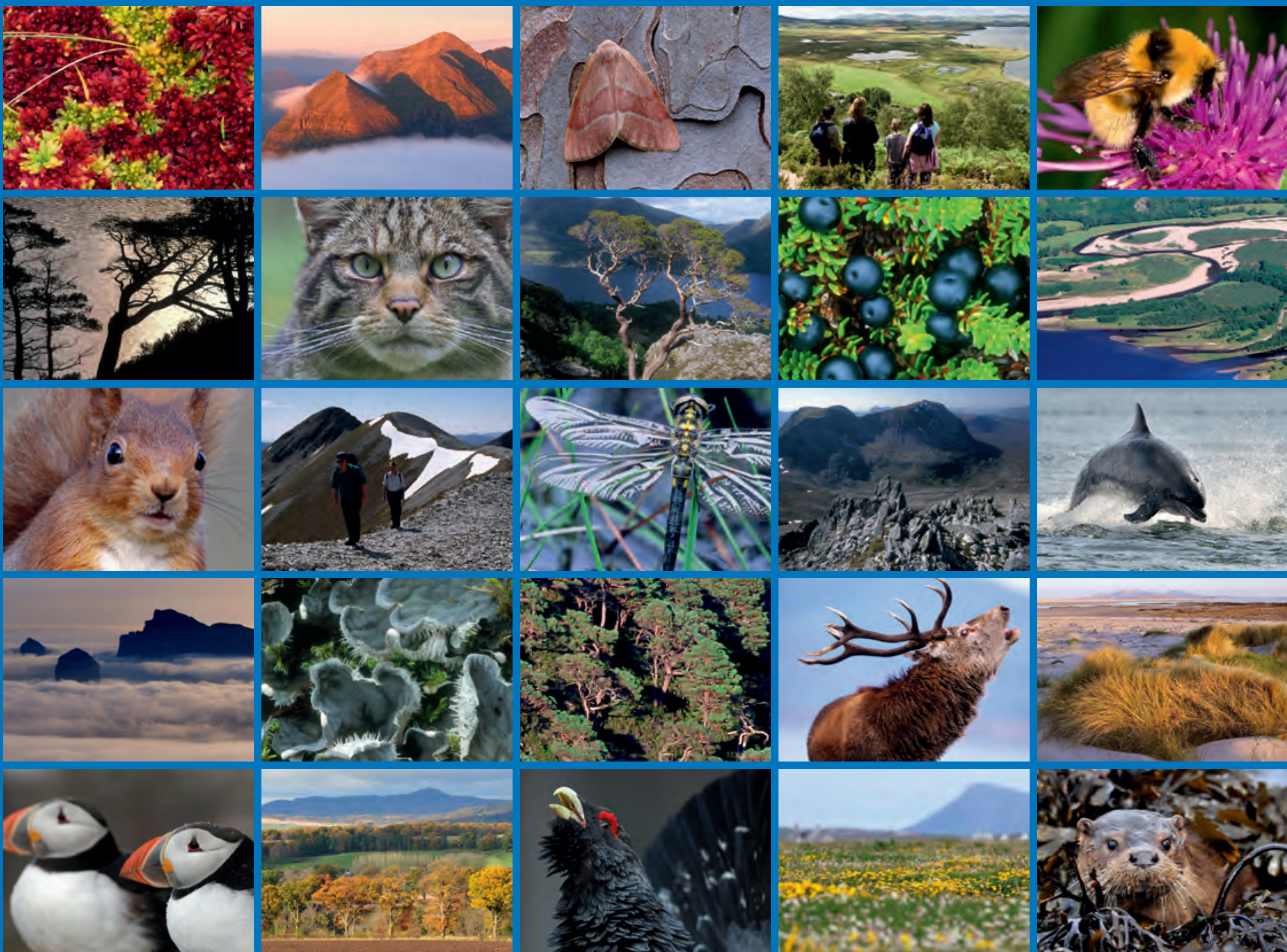
Scottish Natural Heritage
Commissioned Report No. 499

Alder Woodland – Tree condition assessment survey:

Mound Alderwoods Site of Special Scientific Interest and Special Area of Conservation



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COMMISSIONED REPORT

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COMMISSIONED REPORT

Summary

Alder Woodland – Tree condition assessment survey: Mound Alderwoods Site of Special Scientific Interest and Special Area of Conservation.

Commissioned Report No. 499 (Project No. 12483)

Contractor: Forest Research

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Background

This survey was commissioned by Scottish Natural Heritage (SNH) in order to assess the condition of the alder woodland within the Mound Alderwoods Special Area of Conservation, with Forest Research (FR) contributing to the work through a Partnership Agreement.

Defoliation and subsequent dieback of alders within the Mound Alderwoods was noted by SNH personnel between 2005 and 2008 and subsequent *ad hoc* observations have suggested that the condition of the trees has not improved, and may indeed have declined, in recent years. The health of the trees within this area is of particular concern because the Mound is recognised both as one of the country's best examples of Alder woodland on floodplains and as the largest estuarine alderwood in Britain. A better understanding of the nature of the dieback which has affected the trees is required in order to determine its likely cause(s) and thereby ascertain whether particular on-site management measures can be modified or adopted to help promote conditions for good tree health.

Main findings

- Dieback of alders is evident across the Mound Alderwoods but is most severe in low-lying areas closer to the River Fleet and the Abhainn an t-Sratha Charnaig and least severe in more elevated locations around the margin of the site.

- Crown symptoms displayed by dieback-affected trees in the Mound Alderwoods include yellowing of foliage, reduction in leaf size, and progressive death of twigs and branches throughout their entire crowns. These symptoms are dissimilar to those associated with the "alder dieback" syndrome which has periodically occurred in Scotland during the last 30 years which, by contrast, is characterised by rapid mortality of portions of the branching structure of affected trees. However, the symptoms of the dieback-affected trees are consistent with infection by a root pathogen and / or mortality of roots associated with poor growing conditions.

- The root and stem pathogen *Phytophthora alni*, the causal agent of a disease of alders which is often lethal, was isolated from bark lesions on the roots and stems of alders situated in the northern half of the site.

- Root mortality associated with waterlogging was detected on trees in lower-lying areas located to the south of the River Fleet. In these areas, both the rooting depth of the ground vegetation and the characteristics of the soil profiles indicated the presence of a shallow but fluctuating water table.

- Dendrochronological analysis indicates that there has been a general decline in the radial growth rate of alders across the site since the early to mid 2000s. This reduction in growth rate is not restricted to trees which currently show symptoms of dieback. The only exception to this finding was for a population of young and vigorous alders in the southwest of the woodland which displayed a decline in growth in the mid 2000s but a subsequent recovery in growth rate.

- A review of meteorological data for the Mound area suggests that there may have been a slight increase in total annual precipitation at the site over the last three decades. However, no indication was found that there has been an increase in either total rainfall or the number of days of heavy rainfall (>10mm) during the course of the growing season over the same period.

- The policy regarding operation of the sluices which regulate water flow out of the site was changed from one of flood prevention to one of flood response in 2001. It is concluded that both the frequency and the length of time for which the Mound Alderwoods site is inundated at times of flooding will consequently have increased during the last decade. A reversal of this policy change is recommended.

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Acknowledgements

We would like to thank the owners and occupiers of the Mound Alderwoods for permitting access to the site and thereby supporting this project. Thanks are also due to Grace MacAskill for her assistance with the laboratory investigations described here and to Bill Rayner for helpful discussions relating to site history and soils. We are also grateful to Mr Jackie Ross who gave freely of his time to discuss past management of the Mound sluices and certain aspects of site history. Graeme Hendry's help in obtaining historical documentation relating to the site has proved to be invaluable.

Through SNH, James Russell of Transerv Scotland provided information on the recent upkeep and management of the Mound sluices which greatly aided our understanding of recent site history. Finally, the assistance and encouragement of David Patterson and Jeanette Hall of Scottish Natural Heritage throughout the course of the investigation has been greatly appreciated and we thank them for making this cooperative project a pleasant as well as an enlightening venture.

1 INTRODUCTION

The Mound Alderwoods occupies an area of approximately 300 hectares at the head of Loch Fleet, some 5 km southwest of Golspie in the county of Sutherland. Approximately two-thirds of the area consists of a mixed alder / ash wood, with coniferous woodland occupying around 10% of the site and the remainder consisting of small areas of mud flats, heath, scrub, marshes and inland water bodies. The majority of the site is effectively reclaimed land which came into existence at the beginning of the 19th century, when a tidal barrage (the “Fleet Mound” from which the area takes its name) was constructed across the upper part of the Fleet estuary as part of a long-standing government programme to improve the road network in the Highlands of Scotland.

After being cut off from the sea, and under the influence of the River Fleet and its main tributary the Abhainn an t-Sratha Charnaig (hereafter referred to as the River Carnaig), the area was colonised by alder, ash and willow to form the present mixture of dense wet woodland, open fen and brackish lagoons (Figure 1). Due to its situation on a flat plain at the mouth of the Fleet, and to the influence of a sluice system situated beneath the bridge at the eastern end of the Fleet Mound which both prevents the ingress of sea water onto the site and regulates the outflow of fresh water from it, the Mound Alderwoods are periodically flooded. However, a few raised ridges remain sufficiently dry to support an open-structured mature Scots pine woodland.

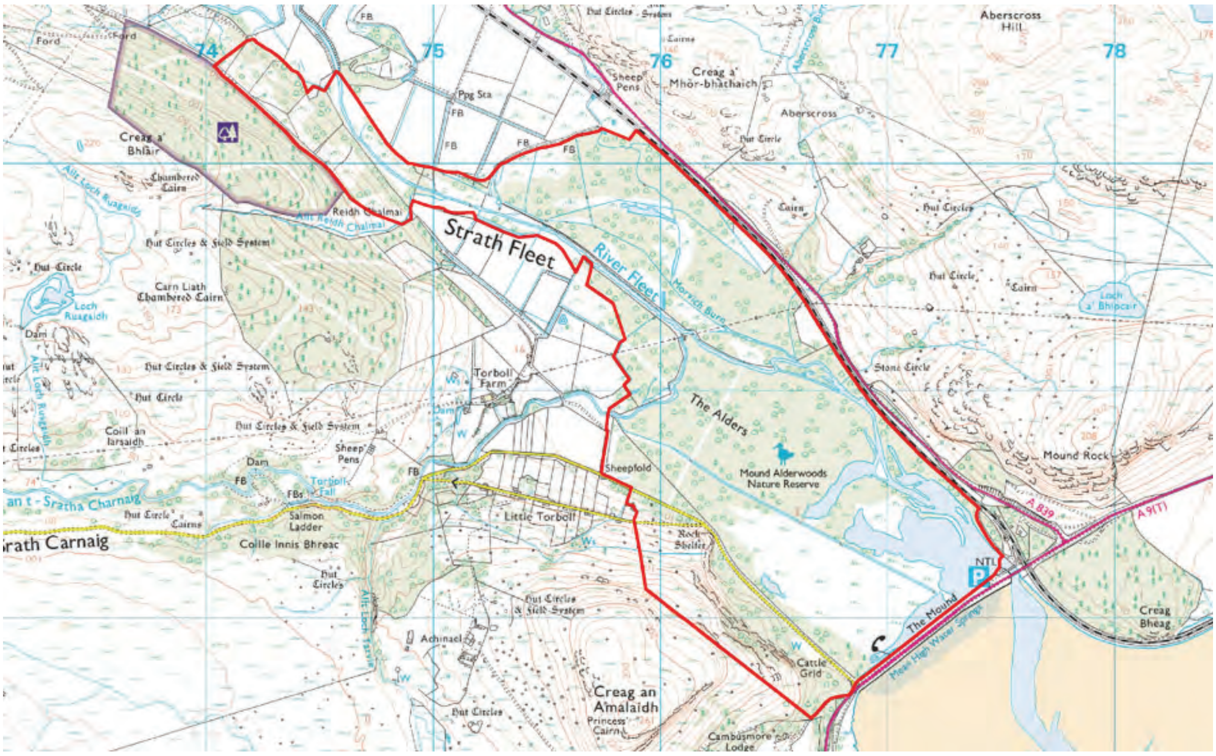

Figure 1: Mound Alderwoods SAC, boundary shown in red. (© Crown copyright and database right [2012] All rights reserved. Ordnance Survey Licence number [100021242])

The Mound is recognised both as one of the country’s best examples of Alder woodland on floodplains and as the largest estuarine alderwood in Britain, and consequently is notified as a SSSI for its wet woodland, saline lagoon habitats and for its breeding wetland birds. The wet woodland is also of international importance; designated as Mound Alderwoods Special Area of Conservation (SAC) and forming part of the Dornoch Firth and Loch Fleet Special Protection Area (SPA) & Ramsar site. Monitoring is carried out at intervals to determine whether the special features for which protected areas have been designated are in a satisfactory condition, and the Mound Alderwoods were subject to such assessments in June 2004 and June 2010. As a result of the monitoring carried out in 2010, it was concluded that the wet woodland was in unfavourable / declining condition due to heavy deer damage to younger trees and the development of an unexplained dieback in a proportion of the mature alders (Anon., 2011)

Although severe defoliation of mature alders within the woodland by the larvae of a Chrysomelid beetle had been noted in successive years from 2005 to 2008 (Anon., 2011) the cause(s) of the dieback of mature trees in the Mound Alderwoods has remained unknown. Defoliation of mature native trees by indigenous insects rarely results in their death, and severe defoliation may be the result of a decline in tree health rather than its immediate cause. There are two diseases which commonly result in the dieback and death of alders and which therefore have a serious effect on populations of these trees in certain parts of Scotland: Phytophthora disease of alder and “alder dieback” (Webber, Gibbs & Hendry, 2004). Phytophthora disease of alder is caused by the aggressive root pathogen *Phytophthora alni*, whilst “alder dieback” is a complex disease which occurs when one or more species of weakly pathogenic fungi colonise the branches and stems of trees subjected to environmental or biotic stresses (Cech & Hendry, 2003). Based upon their known distributions within Scotland, either of these diseases could potentially have been responsible for the decline in the condition of alders occurring within the Mound Alderwoods SAC. Additionally, fluctuations in water level resulting from changes in weather patterns or site management could have contributed to, or caused dieback at the site (Anon., 2011).

A better understanding of the nature of the dieback which has affected the trees within the Mound Alderwoods is required in order to determine its likely cause(s) and thereby ascertain whether particular on-site management measures can be modified or adopted to improve tree health. The following report details field and laboratory studies which were undertaken to this end between August and November 2011, describes the results of those studies and considers future actions which might be taken in order to address the problem of alder dieback at this site.

2 METHODS

Given the range of potential agents and predisposing factors which could be involved in causing the decline of trees in certain areas of the Mound Alderwoods, a detailed pathological investigation to allow the detection of any pests or pathogens either on the aerial parts of the trees or on their roots, and an evaluation of site-related factors (such as soil type) which may have caused or contributed to the poor condition of the trees was undertaken.

An initial walk-through of the site was carried out in order to gain a general impression of the range of symptoms which was evident on the alders and to identify areas where dieback was particularly severe or light. Due to flooding of the Mound Alderwoods at the end of August 2011, it was not possible to gain access to all of the alder stands within the woodland but a sufficiently good view of most areas was available from the internal roadways to allow a relatively complete overview of the condition of trees in different parts of the site to be reached. Having identified particular groups of trees for further study, detailed investigations of, and sampling of tissues from, individual alders were then undertaken in order to determine the nature of any damage or disease which was present (see section 2.1 below).

In addition, tree condition monitoring plots were established within one stand of healthy trees and one stand where alders were affected by severe dieback (section 2.2 below) both to provide a baseline for determining future changes in tree health and to allow subsequent dendrochronological analysis of populations of trees whose condition was known and documented (see section 2.3).

Based upon preliminary findings from the field and laboratory studies, the need for a more complete overview of past site condition was evident and a review of meteorological data, mapping evidence and other sources of information was also undertaken.

2.1 Pathological investigations of trees affected by dieback

Individual alders affected by dieback were first examined for evidence of bark lesions[1] on their branches or stems, and for any signs of fungal fruiting associated with regions of dead bark. Where lesions were detected, samples consisting of bark material or of entire branches / stems were taken for subsequent laboratory investigation. Root excavations were then carried out to determine whether bark death was evident in the structural roots, or necrosis[2] of the fine root system could be detected. Where appropriate (typically but not exclusively when junctions between dead and living tissues were evident), root material was excised for later laboratory study and soil samples taken from around the rooting systems of declining trees.

At each location where detailed examination of trees was conducted, a soil pit was dug to a depth of at least 1 metre, or until further excavation was impossible. Exposed soil profiles were then photographed and examined either *in situ* or, where the water table was too high for this to be practicable, were excised from the side of the pit and taken to dry ground for further inspection.

In the laboratory, portions of all root and soil samples, and lesion material with the pale brown colouration and water-soaked appearance which is often associated with *Phytophthora* infection, were inserted into apple baits which were then incubated for up to 14 days at room temperature. Material from lesions developing within the flesh of the apples

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[1] lesion (n): a localised area of diseased or disordered tissue
[2] necrosis (n): death of plant tissues, usually characterised by a change in colour to brown or black (adjective necrotic)

was sub-cultured onto Cornmeal Agar (CMA) in 9cm Petri dishes and incubated in darkness at 20°C. Fungi developing on CMA isolation plates were identified as far as possible with reference to standard taxonomic texts. Isolations from bark lesions which did not display characteristics suggestive of *Phytophthora* infection were made by excising small pieces of necrotic phloem and placing them onto 2% Malt Extract Agar (MA) in 9cm Petri dishes. MA isolation plates were incubated in darkness at 20°C and fungi developing upon them were identified as far as possible with reference to standard taxonomic texts.

2.2 Establishment of monitoring plots to provide a baseline for future determination of changes in tree health

Two areas within the Mound Alderwoods were identified for the establishment of monitoring plots to provide a baseline for determining future changes in tree health, and to allow certain dendrochronological analysis to be associated with populations of trees whose condition was known and documented. One area (the Carnaig plot) consisted of trees located outwith the region in which clear symptoms of discolouration and decline were evident in the alders, and was selected with a view both to detecting possible changes in the extent of the dieback-affected area within the woodland and to providing information on the past growth of apparently healthy trees *via* dendrochronological study. The second area (the Confluence plot) consisted of trees displaying severe dieback and was selected with a view to quantifying the rate of mortality or recovery in affected trees as well as determining the timescale over which their decline had occurred. At each location, the position of 30 alder stools located away from the edge of the stand containing them was mapped, and each stool was allocated a unique number. The characteristics of each stool (including stem number, dominance and crown width) were then recorded, together with assessments of the condition of each stem and crown (including crown density, severity of dieback and severity of major foliar symptoms). These procedures largely followed the methodology for assessment of tree condition outlined in Innes (1990).

2.3 Dendrochronology of trees within the Mound

Sample plot locations were chosen to reflect differences in site and tree condition within the alder woodlands (Figure 2) ranging from healthy trees growing rapidly and without any outward signs of damage or infection, to poorly growing trees with definite signs of decline. Samples were collected mainly from the two condition plots established for tree health monitoring (FAC and FAH), with additional samples being taken from areas which contained examples of trees in raised positions (FAP flight pond, and FAP railway) and fast growing trees that appeared to be invading new habitat (FAB).

Two different sample types were collected: stem sections and increment cores. Increment cores can only be collected from stems with a diameter greater than 10cm. Stem sections were collected from small trees that had multiple stems originating from each root stock. Only stem sections were collected from the poor health plot (FAC). Samples were cut with a bushman saw, placed in a numbered plastic bag and carried off-site. All stem section samples were placed in an upright position in plastic trays in an outside shelter (to keep direct rainfall off the sample) to air dry slowly for 6 weeks. Core samples were collected using hand held increment borer, which removes a 4 mm diameter core of wood from the outer bark to inner central core of the sample tree. A Garmin GPSmap 60CSx hand held GPS unit was used to record the position of each sample location.

Preparation of both sample types followed standard dendrochronological techniques. For stem sections, the lower section surface (i.e. the one closest to the root collar), was cut or planed to generate a flat level surface free from irregularities. The section was then cut along a radial line, and the edge of the sample prepared with a razor to expose the annual rings for measurement. Chalk was used to increase the contrast between cell types and define annual boundaries. Annual ring measurements were made under a stereo microscope using a moving table connected to a PC to capture ring widths to an accuracy of 0.01 mm. Cores were glued into wooden batons before sanding. A Makita belt sander was used with grits of 240 G followed by 320 G and 400 G, hand sanding with 600 G gave a fine finish to the samples. Buffing with a lambs-wool buff helped clean the surface and facilitate identification of the annual growth ring boundaries. Core samples were scanned at 1200 dpi to produce a pdf image that could be imported into the measurement software package CooRecorder 7.4 (Cybis 2011). These files were converted and imported into CDendro 7.4 (Cybis, 2011).

Crossdating was initiated in CDendro, which allows both correlations of similarity between individual tree ring measurements and visual matching (skeleton plots) to be used. Local chronologies were generated first, then a composite chronology for all samples generated. Crossdating accuracy was checked statistically using COFECHA; flagged ‘problem’ sections were re-checked under a microscope and measurements amended as necessary. Difficult or non-standard and problematic samples were removed from the analysis at this point. Checked data was imported in ARSTAN for final chronology building and generation of standardised ring indices. Ring indices are generated to remove the influence of size related growth and variability due to inter-tree competition etc. The indices are produced by dividing the measured ring width (mm) for each year by the predicted (or modelled) width for that year to generate a unitless index. This process is called standardisation or detrending. For most samples an exponential curve was used to generate the ring indices through a process of interactive detrending, a sub-routine routinely used within ARSTAN.

The resultant chronologies for each site were imported into Microsoft Excel for simple correlation testing against the climatic variables of monthly mean temperature (degrees Celsius) and monthly total precipitation (mm) for the period January 1914 to December 2006 (MET office gridded climatic data). A correlation was deemed significant if the R-squared value was greater than 0.25.

2.4 Review of meteorological data, mapping evidence and other sources of information on past site conditions and management

Historical rainfall data for the twelve 5km squares overlying the catchment of the River Fleet (centred on Ordnance Survey grid reference points NC625075, NC675075, NC725075, NC775075, NC625025, NC675025, NC725025, NC775025, NH625975, NH675975, NH725975 & NH775975) and temperature data for the single 5km square overlying the Mound (centred on Ordnance Survey grid reference point NH775975) were abstracted and examined to determine whether any short- or long- term changes in the weather patterns in the area of the Mound Alderwoods could be detected.

In addition, archived maps belonging to the following series were scrutinised for changes in the nature and extent of watercourses and vegetation within the Mound area over time:
- Admiralty Charts of Scotland
- Ordnance Survey Six-inch to the mile, 1st edition
- Ordnance Survey 25 inch to the mile, 1st edition
- Ordnance Survey Six-inch to the mile, 2nd edition
- Ordnance Survey 1:10,000, current edition
- Ordnance Survey One-inch to the mile, 1st edition
- Ordnance Survey One-inch to the mile, 2nd edition
- Ordnance Survey One-inch to the mile, 3rd edition
- Ordnance Survey One-inch "popular" edition
- Ordnance Survey 1:50,000 current edition

Current management of the sluices at the eastern end of the Mound barrage was investigated by David Patterson of SNH and his findings were supplied to the authors for information, whilst past management was elucidated by an interview with Mr Jackie Ross, the last official "keeper" of the sluices who retired in 2001.

3 RESULTS

Observations of the symptoms displayed by alders were made at each of the locations indicated in Figure 2. Current dieback was not evident on trees located at points 1, 2, 3, 11, FAH healthy plot, Carnaig condition plot, FAB fast growing plot, or FAP rail crossing. These locations were generally slightly elevated in relation to the remainder of the site, being located either at its margin or along access routes where the ground level appeared to have been built up in the past. Elsewhere, the crowns of alders were noticeably thinner and more chlorotic[3] than would be expected in completely healthy trees and their branching systems displayed varying degrees of dieback. Dieback was most severe in the vicinity of point 17, where mortality of occasional mature trees had occurred, and near points 5 and 6 where alder stools bore little foliage and dieback extended from the twigs and fine branches into the structural branches of many trees. Mortality of trees was also evident to the north of the Fleet opposite the length of riverbank between points 5 and 8, although ground conditions at the time of the visits prevented closer scrutiny of these particular alders.

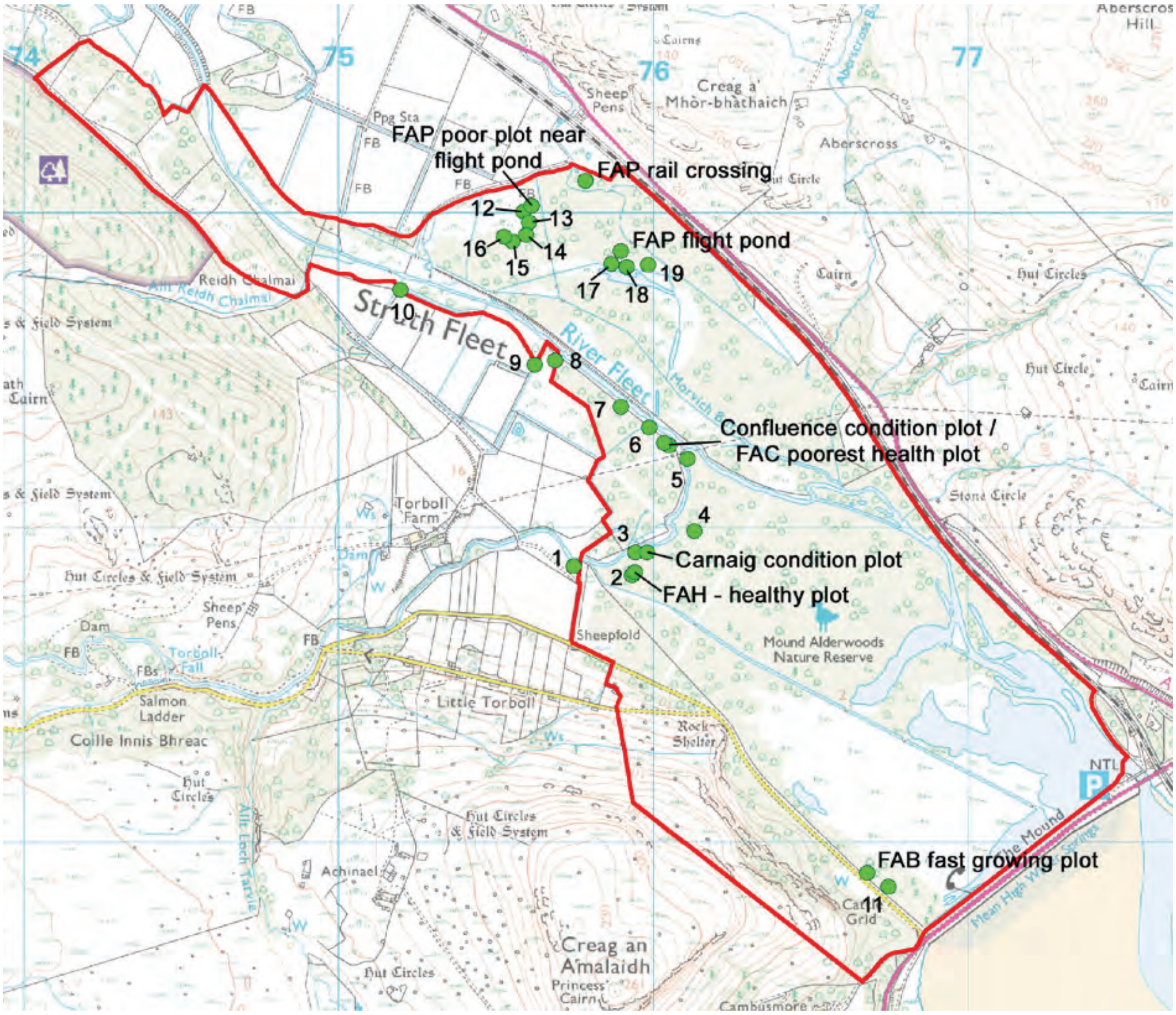

Figure 2: Locations of points at which observations were conducted, pathological investigations undertaken, condition plots established or dendrochronological samples taken. (© Crown copyright and database right [2012] All rights reserved. Ordnance Survey Licence number [100021242])

3 chlorotic (adj): displaying abnormal yellow or yellow-green colouration (noun chlorosis)

Detailed accounts of the pathology of trees displaying symptoms of dieback and investigations of radial growth over time in healthy and affected trees are provided in sections 3.1 and 3.3 respectively.

3.1 Pathological investigations of trees affected by dieback

Detailed investigations of trees with symptoms of current dieback (thin crowns, chlorotic foliage and recent mortality of fine twigs) were made at points 4, 5, 6, 12-19 and near "FAP rail crossing" (Figure 2). Root excavations were conducted and soil pits were dug at points 4, 6, 15, 17, near "FAP rail crossing" and additionally within the stand of healthy alders which included the Carnaig condition plot.

3.1.1 North of the River Fleet

As well as the symptoms mentioned above, trees located to the north of the river Fleet (points 12-19) generally displayed a reduction in leaf size. Stem bleeding in the form of tarry or rusty spots was also evident on a proportion of symptomatic alders (Figure 3). Stem bleeding was always associated with necrosis of the underlying bark, with one or more necrotic lesions typically extending to the base of the affected stems and into one or more of the surface lateral roots (Figure 4). Thorough inspection of the root collars of symptomatic trees without stem bleeding also revealed the presence of ascending bark lesions in many cases.

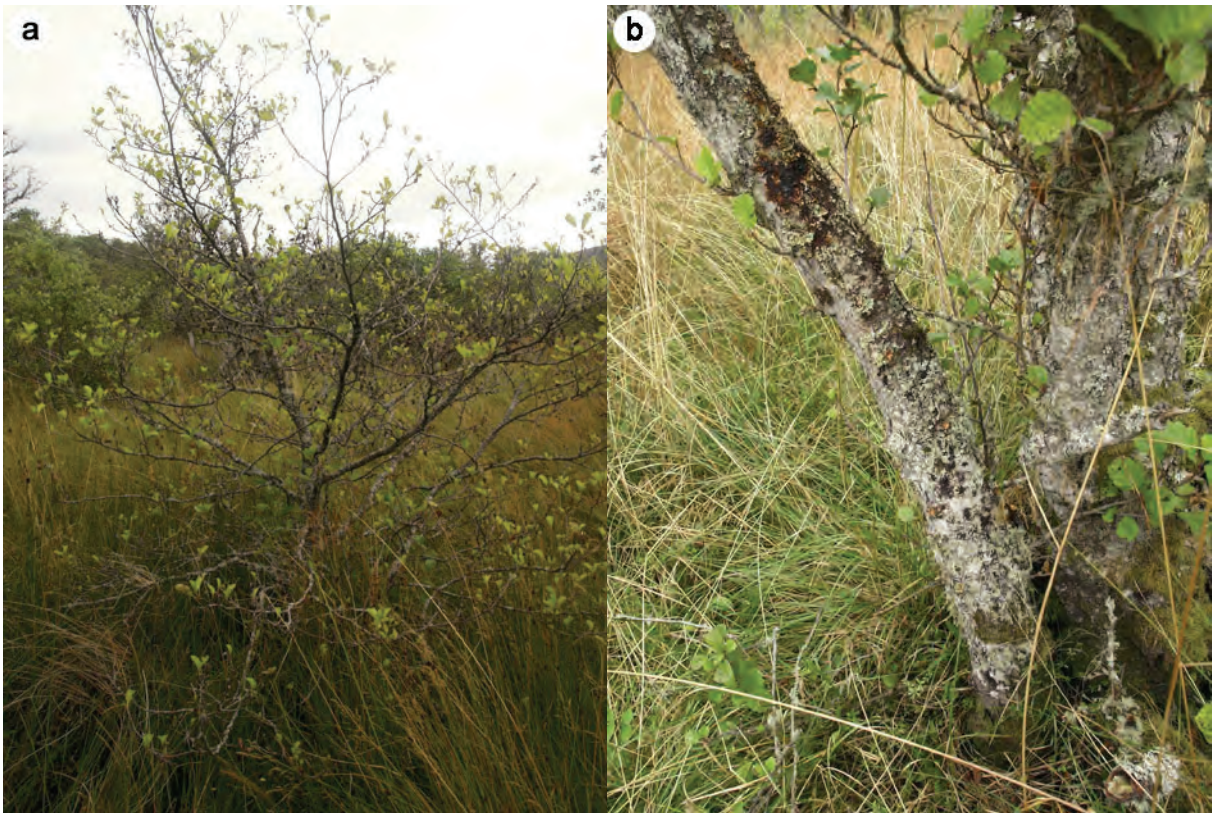

Figure 3: Typical symptoms associated with dieback of alders in the northern part of the Mound Alderwoods: a. Small alder at point 13 with thin crown, small chlorotic leaves and recent mortality of fine twigs; b. Larger alder at point 19 displaying tarry / rusty spotting on stem to a height of 1.5m

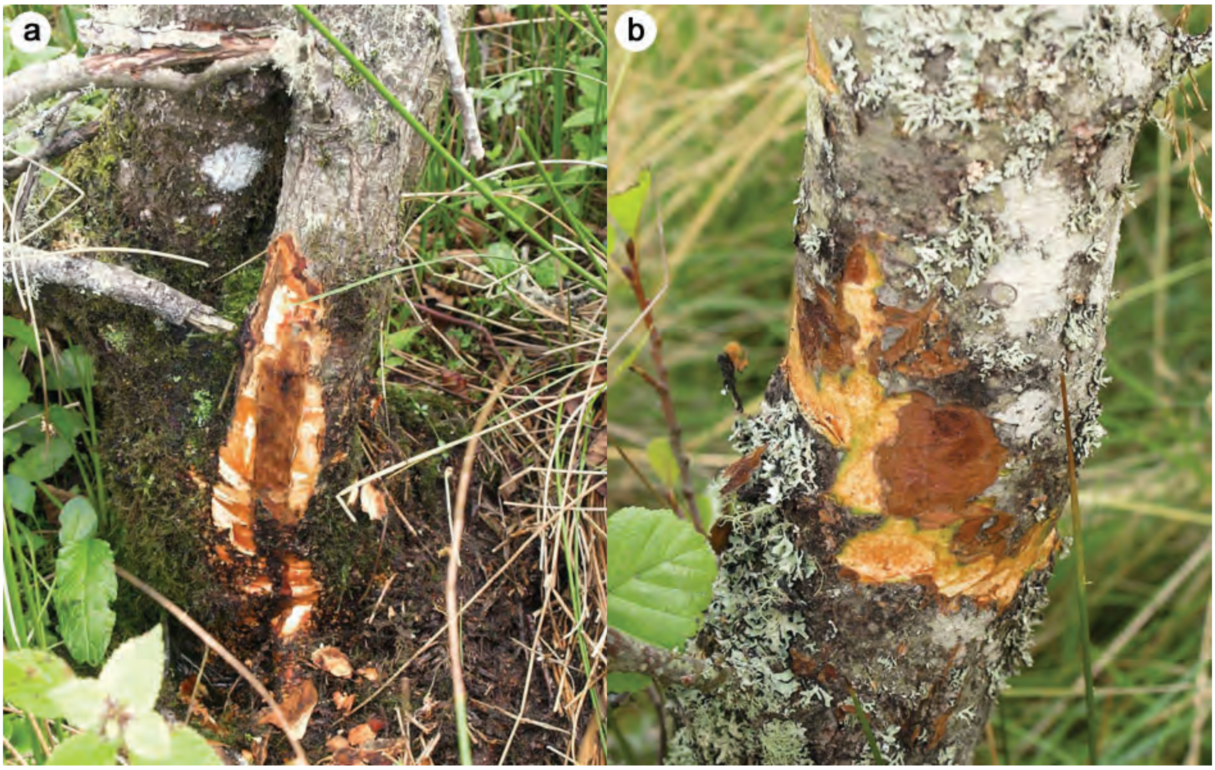

Figure 4: Bark lesions in alder stems from the area north of the River Fleet: a. Lesion extending upwards from root collar and down into surface lateral root on tree at point 13; b. Superficial lesion in outer phloem of tree at point 14.

In addition, occasional trees with tarry spots on their stems were found to have isolated superficial necrotic patches in the phloem[4] which were not connected to more extensive stem lesions (Figure 4).

Laboratory isolations conducted on bark tissue excised from the margins of lesions on the stems of trees at points 12, 14, 15, 16, 17 and 19 yielded cultures of the alder pathogen *Phytophthora alni*. Isolations from root lesions on trees at points 13 and 19, and from soil adjacent to affected trees (containing fine root material but no structural roots) at points 15 and 19 also yielded cultures of *P. alni*. No other potential pathogens were isolated from the samples concerned, nor were any recognised foliar, shoot or bark pathogens detected on moribund[5] or recently dead material collected from the crowns of affected trees. Whilst occasional instances of bud mining by *Epinotia tenerana* and of leaf damage likely to have been caused by *Chrysomela aenea* were noted, insect damage to the trees which were examined had been extremely light during the 2011 growing season.

The nature of the soil in the Mound Alderwoods was broadly similar in all areas which were investigated and consisted of a silty alluvial upper horizon of 10 to 15 cm in depth overlying sand of at least 75 cm in depth which graded into fine shingle of 5 – 10 mm diameter beneath. On the northern side of the Fleet, where the water table was located at 30 – 50 cm below the ground line at the time of sampling, the sand horizon displayed a distinct zonation with an upper light-coloured and well-aerated layer overlying a darker grey (gleyed[6]) layer of more solid texture (Figure 5). Healthy feeder roots of alder were found throughout the friable

[4] phloem (n): the inner bark of the tree located beneath the bark scales which serves to transport sugars within the woody tissues.
[5] moribund (adj): in the process of dying
[6] gleyed (adj): greyish, often mottled appearance resulting from the reduction and partial re-oxidization of iron oxides in the subsurface layers of soil as a consequence of periodic waterlogging.

silt and well-aerated sandy layers but were not detected within the gleyed sand. No attempt was made to reveal structural roots which might have penetrated into the gleyed subsoil in order to determine their condition.

Figure 5: a. Soil pit at point 17 showing upper horizon of silt, lower horizons of well- and poorly- oxygenated sand, and water table level. Note live alder root extending from back face of pit. b. Detail of well-oxygenated (yellow) and gleyed (grey) sand.

3.1.2 South of the River Fleet

Dieback-affected trees located to the south of the River Fleet (points 4, 5 and 6 in Figure 2) did not display the consistent reduction in leaf size which was observed in declining alders on the northern side of the river. Moreover, neither stem bleeding nor stem lesions were detected on the southern trees. Instead, excavations revealed extensive mortality of the fine and structural roots with little or no bark death evident above the level of the root collar. Structural roots were typically found to be alive at their insertion points and for some distance distal[7] to this before a region of variable length (ranging from a few centimetres to a few tens of centimetres in extent) with moribund bark was encountered (Figure 6). No sharp junction between live and moribund bark was present but a gradation of consistency and colouration was evident in both the phloem and underlying xylem[8], with necrotic tissue becoming more water-soaked and darkly stained with distance from the root collar. Distal to this moribund region, structural roots were blackened and water-saturated with the bark often detaching from the underlying xylem which was characteristically stained a blue-black colour.

Moribund regions occurred at various distances along the surface lateral roots of individual trees but originated at a similar depth beneath the soil surface: approximately 20 cm for

[7] distal (adj): towards the periphery of the branching structure (i.e. further away from the stem)
[8] xylem (n): the woody tissue beneath the tree's bark i.e. the sapwood and / or heartwood.

trees at sample point 4, and 10-15 cm for trees at sample point 6 (Figure 2). The water table at these locations was located close to the level of the soil surface at the time of sampling, thus facilitating accurate comparison of the relative levels of different parts of rooting systems even after the soil around them had been disturbed during the process of excavation. Whilst the structure of the soil at these locations conformed to the general description given in section 3.1.1above, gleying of the sandy layer was evident throughout its depth which would be consistent with the soil being wetted up to (or above) the ground line for at least part of the year. Soil removed from below 30 cm in the profile was malodorous[9] and clearly anaerobic. The rooting depth of the ground vegetation in these areas also indicated the maintenance of a relatively high water table throughout the course of the growing season, being located at approximately 20-25 cm at sample point 4 (Figure 6) and 10-15 cm at sample point 6. The presence of hypertrophied lenticels [10]on and near the root buttresses of many alders to the south of the Fleet provided further evidence for a consistently high water table in this area.

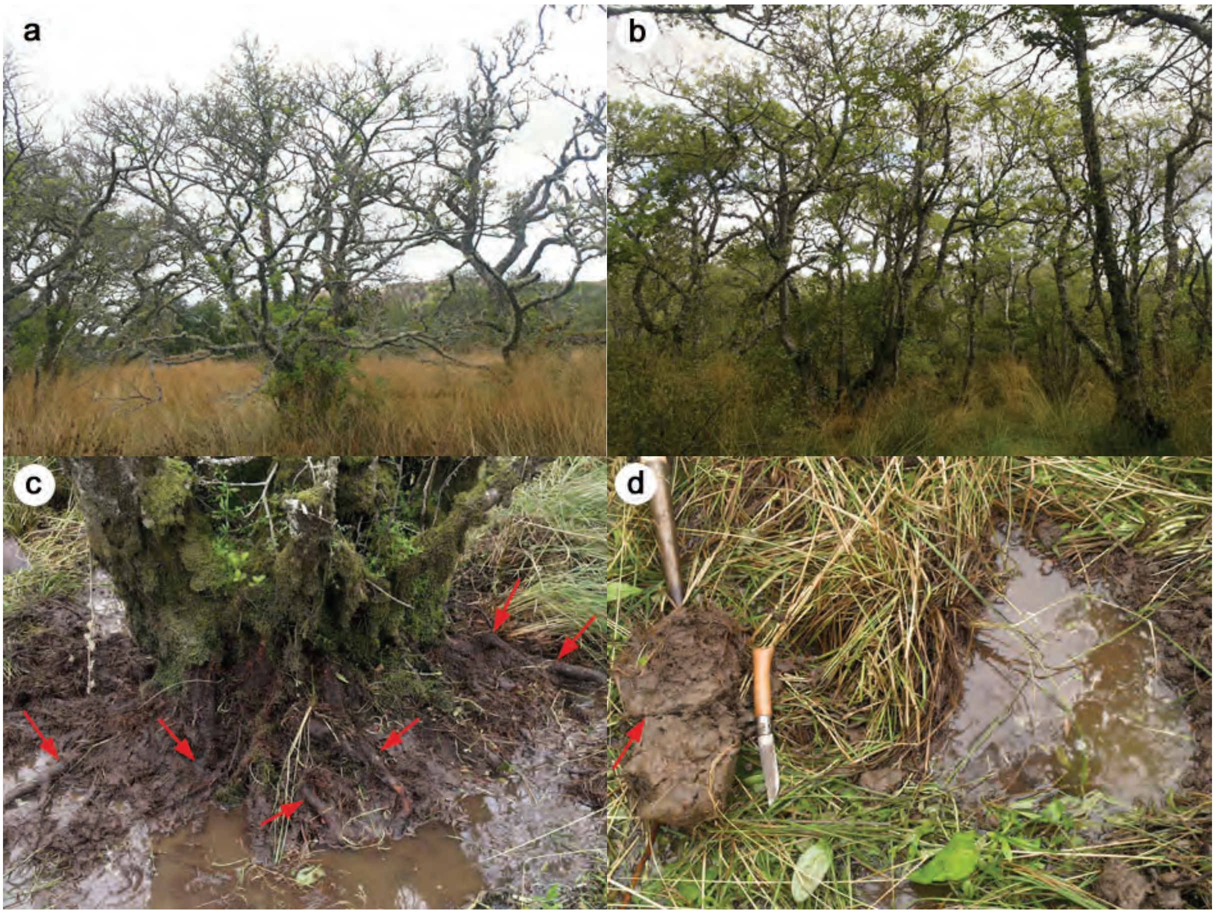

Figure 6: Typical symptoms associated with dieback of alders in the southern part of the Mound Alderwoods. a. Multi-stemmed tree near point 6 with little foliage; b. High but thin crowns of predominantly single-stemmed alders at point 4; c. Root system of tree at point 4 – structural roots are dead distal to the arrowed points; d. Soil pit indicating level of water table (right) and extracted profile (left) indicating extremely limited rooting depth (arrowed).

[9] malodorous (adj): foul smelling
[10] lenticels (n): "breathing pores" in the bark of trees through which oxygen can reach the underlying tissues. Hypertrophied lenticels are abnormally enlarged.

Laboratory isolations conducted on bark tissue excised from moribund roots, and on soil and fine root tissue sampled from the rooting zone of alders affected by dieback, provided no evidence for the presence of *Phytophthora alni* or any other potential root pathogen of alder in the area south of the Fleet. Species of *Pythium,* which often colonise dead or dying organic material in waterlogged conditions and which grow rapidly in laboratory culture, were frequently isolated from the soil samples and could possibly have masked the presence of any *Phytophthora* present. However, dilution of soil samples prior to isolation and use of selective media to suppress the growth of *Pythium* failed to provide any evidence for the involvement of *P. alni* or any other *Phytophthora* species in causing dieback of the southern trees.

Symptomatic branches from affected trees bore a mixture of living, dead and dying shoots which, based upon the crowding of leaf scars which was evident, had grown poorly for several years. The exact age of shoots, or the year of their mortality, could not be determined with certainty *via* an examination of their external features because *Alnus glutinosa* produces no bud scars[11] upon which to base an accurate chronology of extension growth. However, microscopic examination of longitudinal sections through nodes where living and dead branches met revealed that dieback had been occurring at points 4 and 6 since at least 2005 and was progressive in nature, with mortality of at least some branches occurring in each of the subsequent years. No recognised leaf, shoot or bark pathogens were found to be fruiting upon the branches which were examined and, as in the alders located north of the Fleet, only minor insect damage in the form of bud mining and partial defoliation were noted.

The poor growth displayed by affected alders in recent years, the even distribution of shoot and branch mortality throughout their crowns, the absence of any recognised shoot or bark pathogens and the progressive nature of the dieback are all indicative of root system dysfunction in these trees. The apparent absence of any root pathogens associated with the extensive root mortality which was revealed by excavation, the lack of well-demarcated lesions in dying roots, and the diffuse staining observed in the phloem and xylem of moribund and dead roots, constitute strong evidence that waterlogging is involved in the causation of dieback in the area south of the River Fleet. Study of the soil in this area confirms that the water table is elevated and the soil profile below about 30cm is anoxic.

3.2 Establishment of monitoring plots to provide a baseline for future determination of changes in tree health

Monitoring plots were established in one stand of trees where symptoms of dieback were limited (Carnaig plot) and a second stand where severe dieback of alders was ongoing (Confluence plot). Trees within the Confluence plot were characteristically multi-stemmed, with an average of 4.5 stems per stool, and poorly foliated with an average crown density of only 7.2%. Contrastingly, trees in the Carnaig plot were predominantly single-stemmed with high crowns possessing an average density of 61%.

Only a small proportion of the alders within the Carnaig plot displayed any symptoms of dieback with mortality of fine twigs adjudged to be absent or scarce on 77% of stems, whilst abundant or total dieback of the twig structure was recorded for more than 60% of the live stems in the Confluence plot (Figure 7). Twenty-three percent of stems over 7cm in diameter within the Confluence plot were dead with half of these having died recently (within the last 2 years) as indicated by the state of preservation of their fine twig structure and bark. Whilst 18% of the stems over 7cm in diameter within the Carnaig plot were dead, all were

[11] bud scars: visible scars on the bark of the shoots and branches of most tree species which indicate the position of the scales which originally enclosed a bud. The distance between consecutive sets of bud scars provides an indication of the length of the shoot which was formed in a particular year.

long-dead and most belonged to the 7-15cm diameter class which had clearly been suppressed by the dense overstorey.

The chief value of these plots lies not in the information regarding the current health of the trees summarised above but in the potential to re-assess the same trees in future to provide an accurate evaluation of any changes in condition which may occur within these alder populations over time. Full details of the layouts and assessment details for these plots are therefore provided in Appendix 7.3.

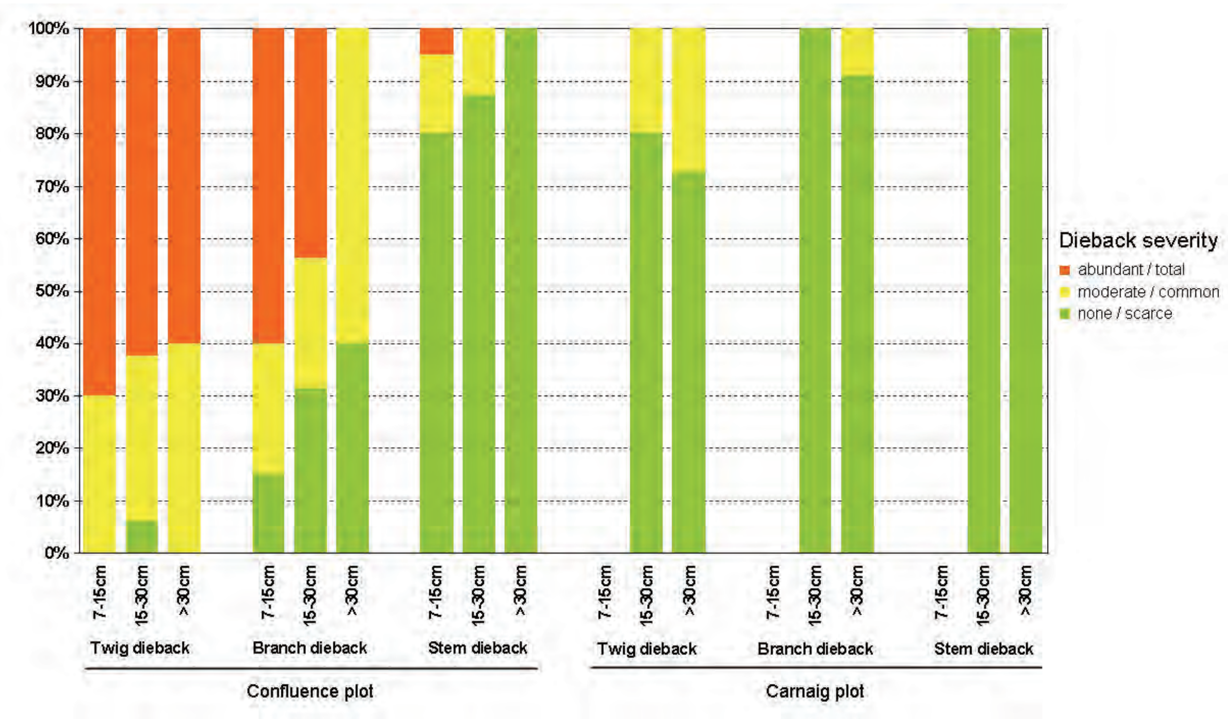

Figure 7: Proportions of living stems in different diameter classes displaying twig, branch and stem dieback of varying severities

3.3 Dendrochronology of trees within the Mound

A total of 49 individual alder and 9 ash tree samples were collected and analysed from four main areas. The oldest alder samples were 173 and 167 years old (recruited in 1858 and 1873 respectively) and were both located near the railway crossing in the north western corner of the site (FAP, Figure 2) on relatively dry ground. This site had predominantly young trees in a matrix of older mature and over mature individuals (Figure 8). A major period of recruitment occurred on this site 60 – 80 years ago (1930 – 50) especially in the area near to the flight pond.

The area near the healthy plot (FAH, Figure 2) also had a wide distribution of ages (see Figure 8) with a mix of old mature trees from the initial establishment phase (1830's – 70's) and another more recent recruitment from 1910 onwards. This site included numerous ash trees of which the oldest sampled was recruited around 1870 (133 years of age), while others were recruited in the late 1920's and 30's (Figure 9).

The youngest recruits were from the unhealthy plot (FAC, Figure 2) near the river confluence, and samples collected from an area close to the flight pond near to an area of cut grass. Here the age distribution was restricted to trees recruited between 1934 and 1974. Although larger, and presumably older trees, existed in the area close to the trees on the raised bank of the road, these were not aged due to rotten centres.

Fastest growth was recorded on the young alder recruits intermixed with Scots pine at the dry south eastern part of the site (FAB, Figure 2). All these trees were of very close age all having been recruited in the late 1950's.

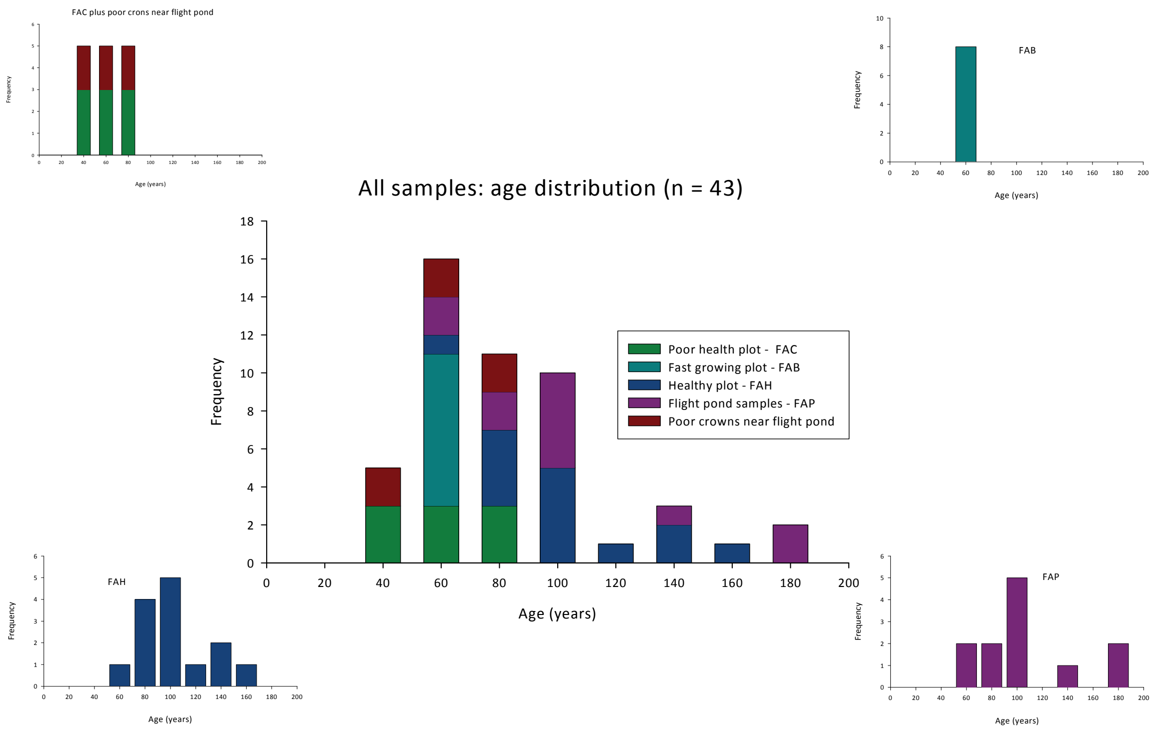

Figure 8: Age distributions for the alder samples.

Interpretation of the age distributions would benefit from detailed management history for the site. It is possible that a change in management of the area occurred in the late 1890's to 1900 which allowed the rapid recruitment of a cohort of young alder. Another such recruitment period occurred between 1950 and 1960. However, care must be taken interpreting these trends as the pattern could reflect the sampling process and not be completely representative of the true age distribution across the entire site. It is interesting to note that many poor-crowned trees are located in areas of restricted age distribution and are relatively young compared with other sampled areas.

In addition to the alder trees that were sampled, several European ash (*Fraxinus excelsior*), which were intermixed with the alder in the healthy plot were sampled to act as a comparison between two species growing on the same site. The ash age distribution is presented in Figure 9.

Both alder and ash samples were collected at plot FAH and Figure 10 allows a comparison of the relative growth of the two species on the same site. Interpretation of the diagrams, with reference also to the individual ring patterns seen during analysis, suggests the site was occupied by some old alder (1860's) but that most recruitment of alder and ash in this area occurred in the 1880's. The growth curve shows a decline between 1880 – 1920 which is likely to be due to inter-tree competition due to rapid recruitment and initial growth of alder and ash on the site. This is followed by a long period of relative steady growth, although some variability can be seen probably due to tree deaths and short term climatic fluctuations. Of particular note is the decline in growth noted in the alder in the early 2000s which is not replicated in the ash. Indeed, it appears that the ash have increased in growth in response to the slight decline in the alders' vigour; although the time periods for analysis are short and the growth pattern changes of the two species could be unrelated.

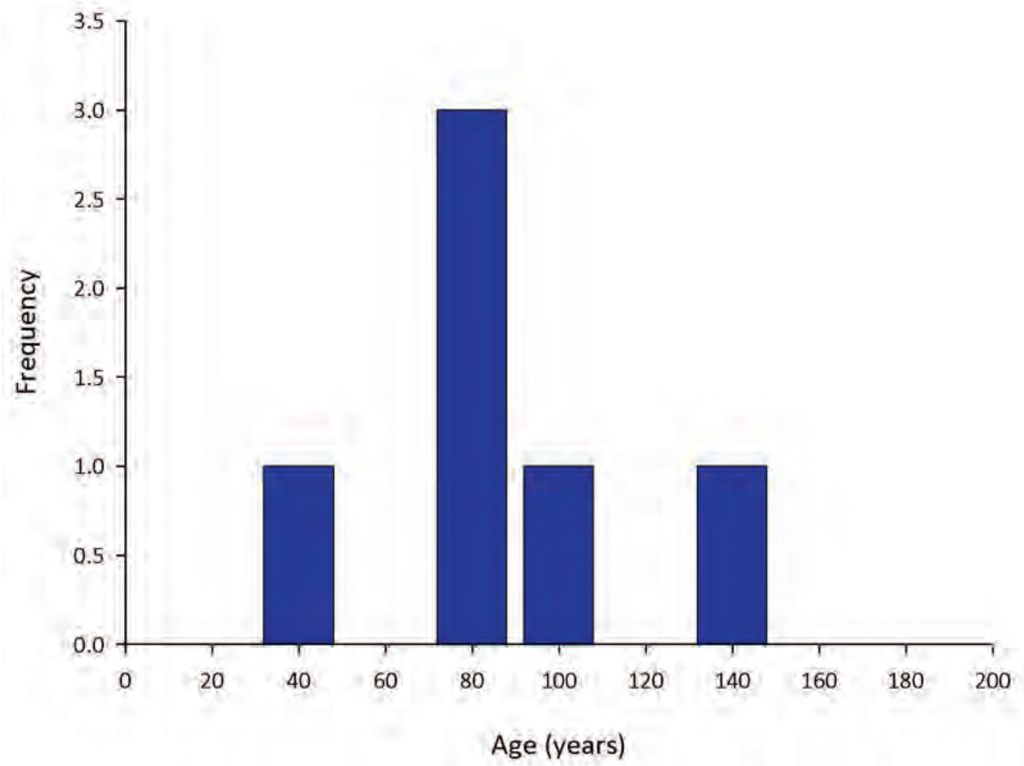

Figure 9: Age distribution for the ash samples

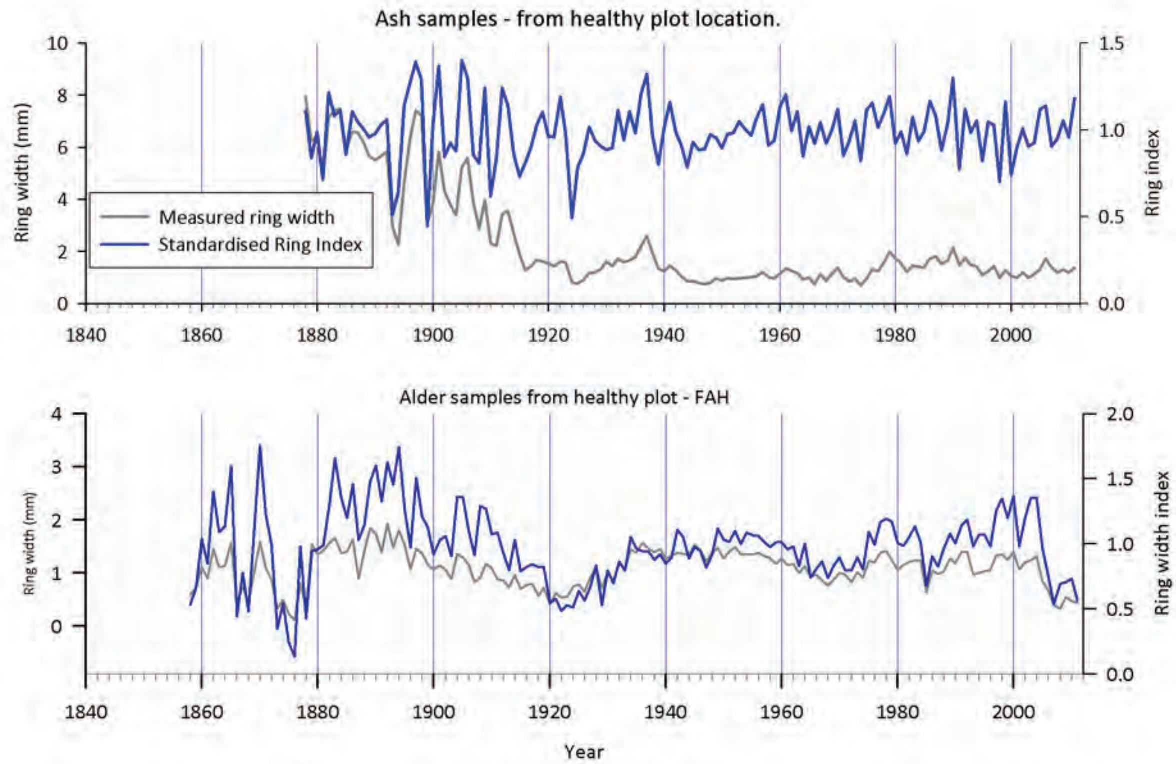

Figure 10: Annual ring growth patterns for the healthy plot alder and the intermixed ash. Note the different Y-axis scales. The alder show a decrease in growth in the last 10 years that is not replicated in the ash samples.

Interpretation of the tree growth for the flight pond and healthy plot samples is rather similar. Both sites show a period of recruitment onto the site where existing trees (the oldest) were growing rapidly. There followed a period of growth decline, most likely associated with inter-tree competition for space and resources, then a long period of stable growth (between 1880 to 2000 for FAP and between 1920 and 1990 for FAH). This is most easily seen for the healthy plot by comparing the recruitment periods (Figure 8) and the growth curves: a decline is associated with the start of recruitment in the late 1890's.

All samples show a reduction in growth (in standardised Ring Index): since the late 1990s in the case of the poorest plot (FAC) and since the early 2000s at all sites (Figure 11). Only the faster growing young alder on the drier site (FAB) show a recovery from this initial decline in growth; all other samples have continued to decline although the rate and extent differs between samples. This is more easily seen when a reduced growth curve period is plotted (Figure 12)

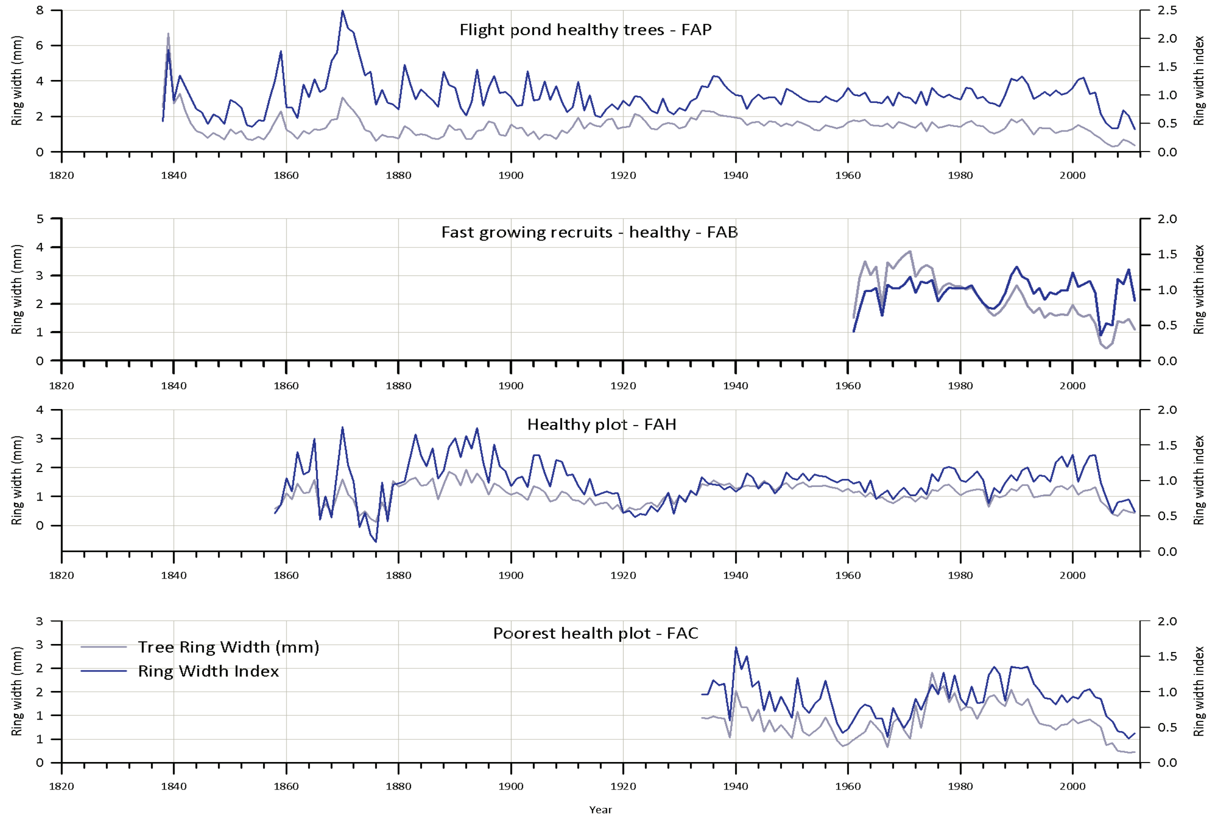

Figure 11: Growth curves for all alder samples. Note the different scales for the y- axis.

Closer examination of the growth curves for the last 60 years (Figure 12) clearly show a period of reduced growth over the last decade. However the decline appears to begin at different dates in each sample location: earliest in the poorest health plot (FAC) and most recently in the healthy plot FAH. Only the young fast growing trees associated with the Scots pine in the south east location (FAB) show any recovery to this decline. This rate and severity of decline is not replicated elsewhere in the history of the samples.

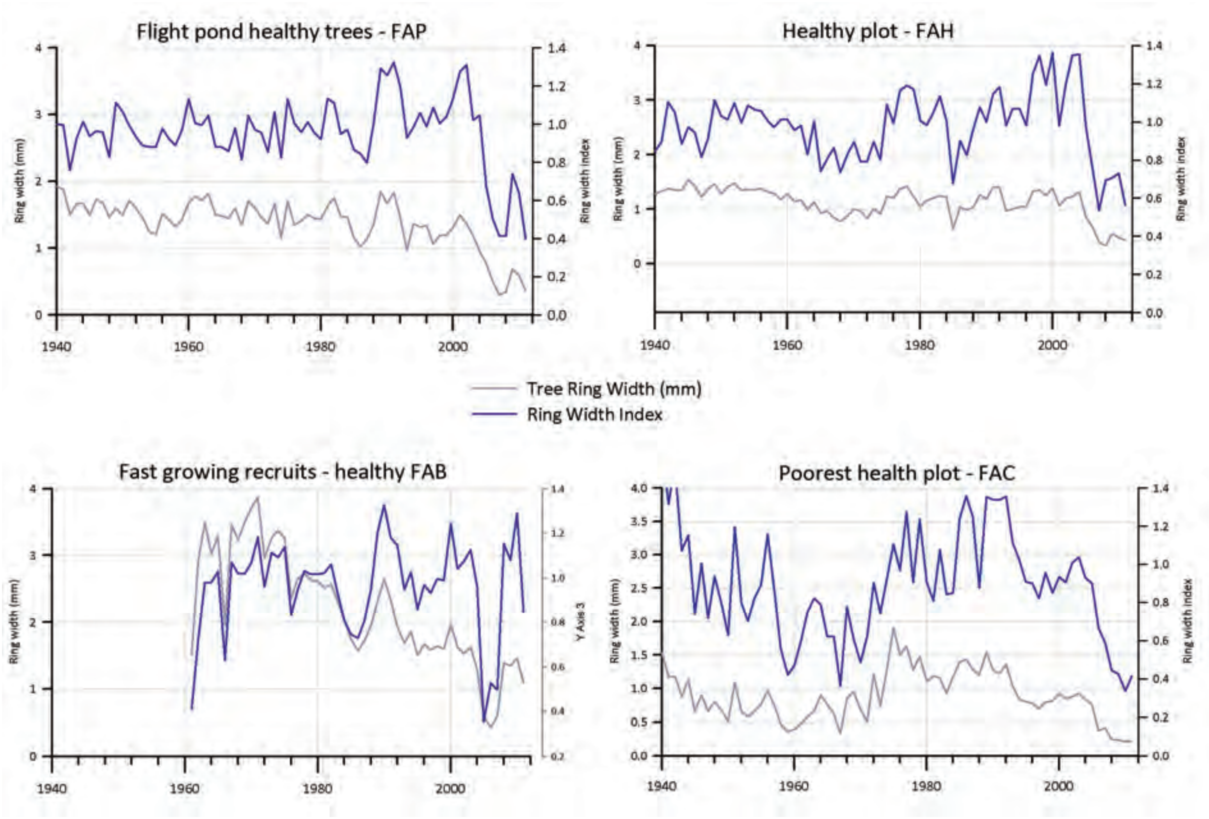

Figure 12: Comparison of growth curves for the alder samples since the 1940s

A number of correlations between ring growth curves and climatic variables (mean monthly air temperature (^{o}C) and monthly precipitation (mm)) are shown in Appendix 7.1. Initial interpretation suggests the existence of a strong correlation between ring growth and temperature but only for the healthy plots. Precipitation is strongly positively correlated with the healthy plot (FAH) for the period between January and August. More interpretation of these results is necessary, and further analysis (removing autocorrelation) will be required.

3.4 Review of meteorological data, mapping evidence and other sources of information on past site conditions and management

Inspection of monthly mean data for the period 1914-2011 revealed no clear trends for a long-term increase or decrease in either rainfall in the River Fleet's catchment area, or temperature at the Mound Alderwoods site. This was the case irrespective of whether data for the entire year or only for the period in which trees would be physiologically active was considered. When data for recent decades was summarised (Table 1 to Table 3) no short-term trends in either the number of days on which heavy rainfall (>10mm) occurred, or in the mean temperature at the Mound, were detected. Total rainfall figures suggest that there may have been a slight increase in annual precipitation in the Fleet catchment over the last three decades (Table 2). However, this increase has been restricted to the autumn and winter months: no indication of an increase in the level of rainfall during the recognised growing season (May to August) or the "extended growing season" during which trees would not be dormant (April to September) was detected (Table 2).

Table 1 – Mean number of days per year in which rainfall exceeded 10mm in the Mound Alderwoods catchment, shown for three different periods in five consecutive decades.

	Mean number of days per year with >10mm rainfall in period:		
Decade	January to December	April to September	May to August
1960s	28.4	12.3	8.4
1970s	25.7	10.0	6.3
1980s	30.3	10.4	6.7
1990s	32.4	12.3	6.8
2000s	31.3	11.2	6.9

Table 2 – Mean total rainfall per year in the Mound Alderwoods catchment, shown for three different periods in six consecutive decades.

	Mean total rainfall (mm) per year in period:		
Decade	January to December	April to September	May to August
1950s	1020.1	441.5	295.5
1960s	969.7	435.2	302.3
1970s	919.6	430.9	302.7
1980s	1003.3	440.6	308.3
1990s	1059.3	430.4	301.6
2000s	1140.8	431.6	296.3

Table 3 – Mean monthly temperature (°C) in the Mound Alderwoods area during three different periods of the year in six consecutive decades

	Mean monthly temperature (°C) in period:		
Decade	January to December	April to September	May to August
1950s	8.0	11.3	12.4
1960s	7.8	11.2	12.2
1970s	8.0	11.3	12.5
1980s	7.9	11.3	12.5
1990s	8.3	11.7	12.7
2000s	8.8	12.2	13.3

Examination of the historical maps which are available for the Mound Alderwoods area shows that tree cover was extremely restricted in 1845, approximately 30 years after the construction of the tidal barrage (Figure 13). Indeed, the distribution of the trees which are shown suggests that they might well have been established before the Mound was built.

No signs of drainage or other earthworks within the area of the Mound Alderwoods are evident on the 1845 Admiralty map but such features are clearly visible on the first Ordnance Survey map based on a survey conducted in 1873, which shows that a number of major drainage channels had been dug across the site in the intervening period. By 1873 it is also clear that tree cover within the Mound had reached almost its current extent, although the composition of the woodland which is indicated suggests that conifers were quite widely distributed across the area. Little alteration in the disposition of the water courses within the site is seen after 1873 but there is a strong indication that woodland composition changed, and this is particularly evident in the southern corner of the site where the maps based on surveys in 1909 and 1928 show the presence of an almost pure conifer stand. Contrastingly, current mapping evidence shows this area of the site as having a covering of scrubby vegetation with no established woodland cover in the area.

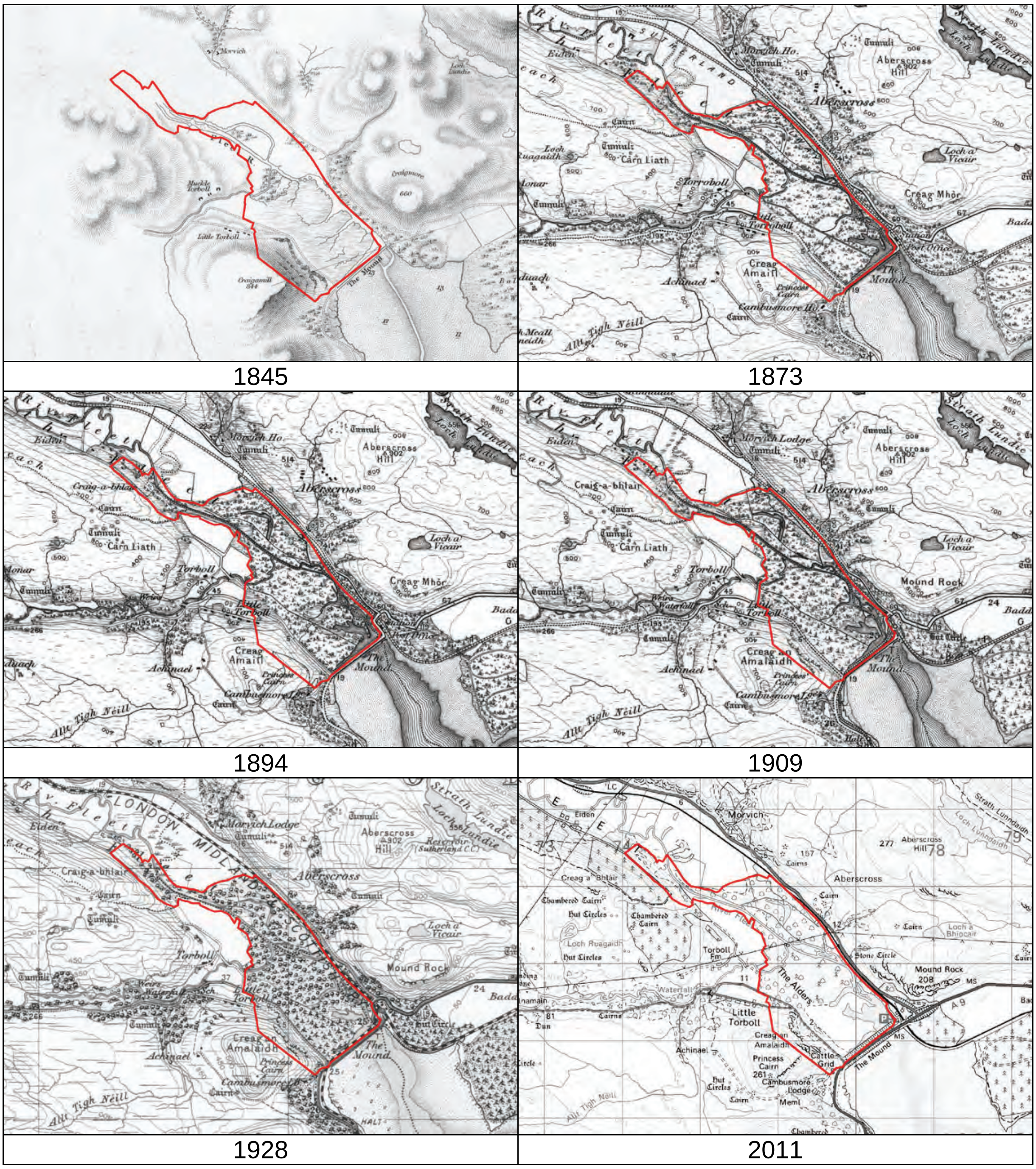

Figure 13: Historical 1 inch maps (or equivalent) of the Mound Alderwoods area from 1845 to the present. The year of the survey or revision upon which each map is based is shown below it. (© Crown copyright and database right [2012] All rights reserved. Ordnance Survey Licence number [100021242]).

Larger scale maps of the Mound Alderwoods based on surveys in 1873 (6 and 25 inches to the mile), 1904 (6 inches to the mile) and the most recent data (1 centimetre per kilometre) provide more insights into historical changes on the site. The 1873 survey in particular indicates that the earthworks and drainage which were carried out after 1845 were both significant and carefully managed. The major drain running from northwest to southeast across the southern part of the site is shown to be connected to the River Carnaig at its northern extremity, with a sluice located at the junction between the two water courses (Figure 14a). This suggests that the flow of the Carnaig into the main body of the woodland could be regulated to some extent by controlling the amount of water diverted along the drain. Furthermore, a substantial length of the main stem of the Fleet is shown as having been embanked (Figure 14f), presumably to protect the adjacent land from inundation when spates of normal severity occurred. As a consequence of this, a large meander in the river located in the northern half of the site which the 1845 map shows as still being part of the River Fleet itself, was cut off to form what is now a flight pond (Figure 14g).

The composition of the woodland cover indicated for the southern half of the site in 1873, with significant downy birch and conifers components (Figure 14b & c), differs substantially from the current mixture of species in this area. In line with the changes evident on the one inch maps mentioned above, the larger scale maps also indicate that the relative proportions of broadleaves and conifers in the extreme south of the site changed markedly during the late 19th century until a pure conifer stand with clear signs of stand management in the form of rides was present by 1909 (Figure 14c & d). This area is now dominated by willow scrub grading into mixed alder / downy birch as reflected by the current map's symbology (Figure 14e).

There are relatively few primary sources of information on the construction and early management of the Mound and these records are not generally cited in recent accounts of the area's history. The most important of these records are the reports of the Commissioners for Roads and Bridges in the Highlands of Scotland (later known as the Commissioners for Repair of Roads and Bridges in Scotland) produced between 1813 and 1861, extracts of which are contained within Appendix 7.2 of this report. Briefly, the idea of placing a barrage across Loch Fleet was proposed to the Commissioners in 1812 and an estimate of the cost of the works was obtained by them, together with an assurance of a contribution towards the expense of its construction from the Marquis of Stafford. The access roads to the site of the Mound on either side of the estuary were completed during the course of 1813 and 1814, with the aim of constructing the Mound barrage itself during the summer of 1815. As events transpired, only the bridge at the eastern end of the barrage (which initially consisted of four arches) and part of the Mound itself were completed by October 1815, and it was not until the 18th June 1816 that the barrage was sealed against the incoming tide following an abortive attempt to do so earlier in the same month.

The initial operation of the sluices, designed to prevent the ingress of seawater but allow fresh water to flow out of the area behind the barrage, was clearly not without problems. Rock cutting was needed in order to divert the direction of the water flowing under the bridge so that it ran "direct upon the sluices", and the gates at twelve feet in width could not be "commanded without machinery" (winches) which were installed within 3 years of the Mound's completion. Writing in September 1819, Southey (1929) noted that: "Lord Gower allows a man a guinea per week and a cottage to live in, to take care of the mound, and lift these doors every tide, as soon as the tide falls, and before the weight of water on the river side suffices to lift them. This is done not because any danger could possibly accrue to the mound, but for the sake of draining the land as soon as possible".

Southey could not have been more mistaken. In December 1831 a flood in Strathfleet raised the water level behind the Mound to within 18 inches of its summit, damaging the barrage and coming close to breaching it. As a result, an additional two arches (and corresponding sluices) were added to the bridge at the east end of the Mound by 1835 to afford additional capacity for "the passage of the highest Floods". The need to retain a keeper charged with opening the sluices was still recognised and, when the original incumbent was "incapacitated from old age" in 1861, discussions for his replacement were quickly put in train "as serious damage might occur by any neglect in opening or shutting the sluices while the river is in flood".

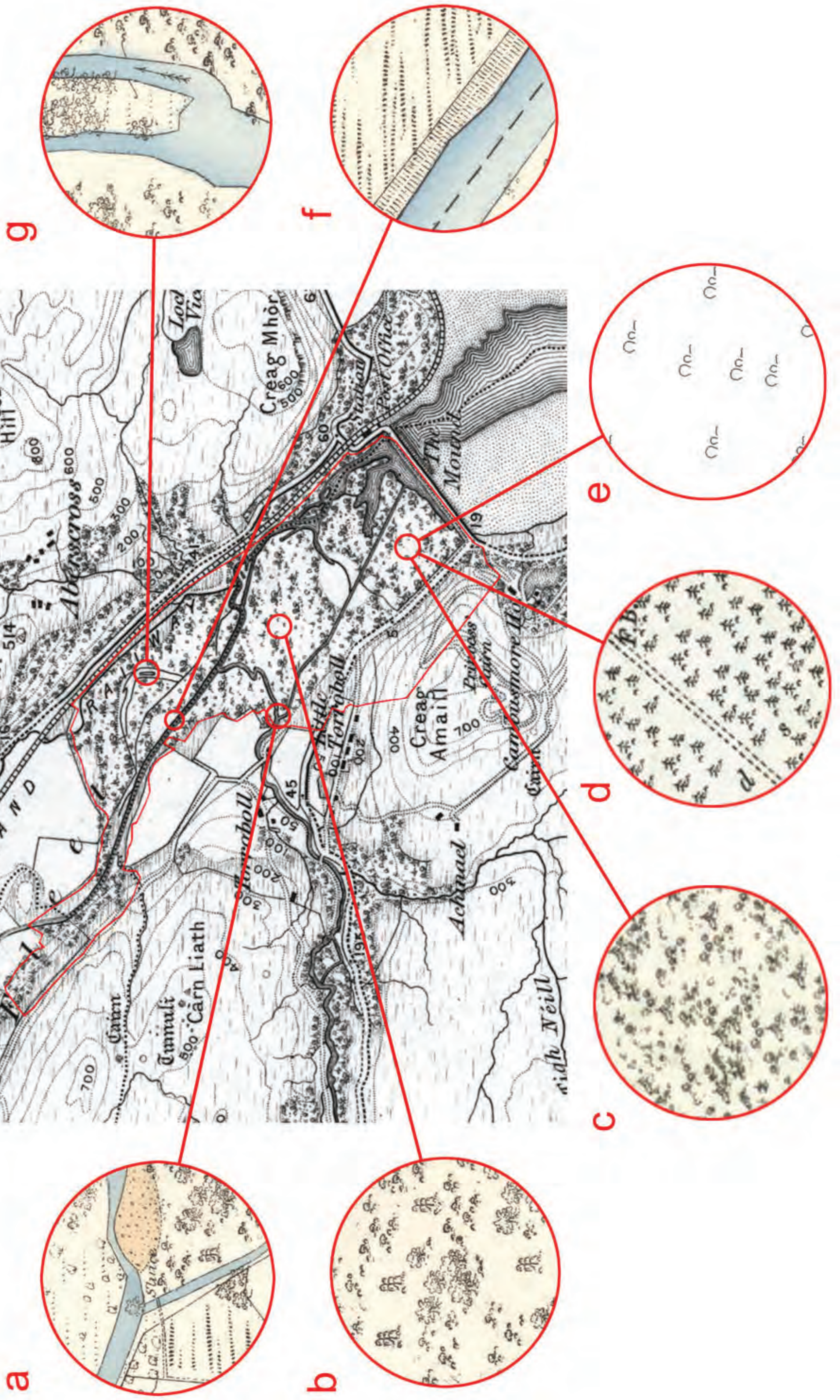

Figure 14: Extracts from historical 6 inch (or equivalent) and 25 inch maps of the Mound Alderwoods area from 1873, 1909 and the present day (a 1873; b. 1873; c. 1873; d. 1909; e. 2012; f. 1873; g 1873). (© Crown copyright and database right [2012] All rights reserved. Ordnance Survey Licence number [100021242]).

The last official sluice-gate keeper at the Mound, Mr. Jackie Ross, retired in December 2000 shortly before the responsibility for the maintenance and operation of the sluices transferred from Highland Regional Council to the trunk roads operating company “BEAR Scotland”. Mr. Ross confirms that until 2001 the manual operation of the sluice gates to increase the water flow out of the area immediately upstream of the Mound was at the keeper’s discretion and that no contact from the council or local landowners was required or expected before the keeper opened the sluice gates in order to prevent inundation of the lower reaches of the Fleet catchment. Whilst this action was most commonly required over the autumn and winter, it was not unusual for the sluice gates to be opened manually during the course of the spring or summer. Mr. Ross estimated that flow through the sluices was increased by at least 50% as a result of manually opening them to their full extent. There is no water height gauge either at the Mound or elsewhere in the Fleet catchment and the height of the water in relation to the protective grille upstream of the sluices was therefore employed as an indicator of when manual operation of the gates might be necessary: when a metal bar approximately half way up the grille was at or near the water’s surface and rain had been falling or was forecast, manual opening of the gates was usually carried out. Opening of the gates was not specifically logged, but Mr. Ross suggested that inspection of the keeper’s timesheets could be undertaken (if they have been retained) in order to construct such a record.

Having lived and worked in the area for many years, Mr Ross was also able to provide some useful observations on the past composition and management of the Mound Alderwoods. He noted that the drainage ditches in the area had last been cleared to improve water flow at some stage in the late 1940s or early 1950s and also confirmed that an almost pure stand of Scots pine had existed at the southern corner of the site until the 1950s when a contractor from Rogart was employed to harvest the trees. Mr Ross’s general impression is that the area is not being managed as assiduously now as it has been in the past and he suggested that silt is building up in the vicinity of the sluices because they are no longer being fully opened: flow rates are consequently inadequate to keep the water channel clear.

From notes and correspondence relating to the operation of the sluices since 2001, it is clear that there was a lack of clarity over who was responsible for operation of the Mound sluices immediately after “BEAR Scotland” assumed responsibility for the management and maintenance of the A9 in Sutherland. In March 2002, the Scottish Executive Roads Division took the view that they were responsible for overseeing the maintenance but not the operation of the sluices, and were aware that the sluices had not been manually opened in the preceding year. Work to refurbish the sluices was ongoing between March and June of 2002 (carried out by R. J. Macleod), during which period their use would have been curtailed. In July 2003, responsibility for the manual operation of the sluice gates was acknowledged by BEAR Scotland who wrote to landowners to provide them with an emergency contact number which was to be used to request opening of the gates “in event of flooding of the fields and land upstream of the Mound Sluices”. Whether any requests to open the gates were made to BEAR is currently unknown but the arrangement clearly represented a change from the active policy of flood prevention which had operated for the preceding 187 years, to a reactive policy of flood response.

BEAR Scotland issued a tender document for repairing the winching mechanism associated with the sluices in November 2003, stating that: “The winches used for the opening of the sluice gates are extremely old and worn and as such, well beyond economic repair. Their condition has resulted in safety implications in their operation and an operator has been injured”. The remedial work, which included replacement of the existing winches, was carried out by Isleburn, Mackay & Macleod in April 2004. The maintenance and management responsibilities for the Mound sluices passed to Scotland Transerv in April 2006 but the policy on manual opening of the gates which BEAR had put in place in 2003 remained unchanged. Transerv report that they contacted both Sutherland and

Cambusmore Estates in January 2008 to remind them of the call-out procedure but have not received any request to open the Mound sluices from April 2006 to the present.

4 DISCUSSION

4.1 Causes of current dieback in alders within the Mound Alderwoods SAC

Alders within the Mound Alderwoods SAC are currently suffering from dieback which was first noted in the mid-2000s. The work reported here indicates that dieback is not attributable to a single cause but to at least 2 agents which undoubtedly interact with each other: the alder pathogen *Phytophthora alni*, and elevated water levels resulting in waterlogging of the trees.

Trees located to the north of the River Fleet displayed classic symptoms of Phytophthora disease of alder in the form of uniformly thin crowns, production of small yellow leaves and exudation of tarry spots from their stems in association with bark lesions ascending from the stem base (Webber, Gibbs & Hendry, 2004). Isolation of *Phytophthora alni* from stem and root lesions, and from soil collected from around the roots of diseased trees in this area, provided definitive evidence of the nature of the malady affecting these alders. Phytophthora disease of alders was first recorded in southern Britain in 1993 and by the late 1990s had been recorded in riparian alders in a number of locations in Scotland ranging from the River Tweed in the South to the River Spey in the north. It is therefore probable that *Phytophthora alni* has reached, or has been unwittingly introduced into, the Mound Alderwoods site within the last ten to fifteen years. The Mound now represents the most northerly site at which the disease has been recorded in Britain.

Alders in the area south of the River Fleet did not display the tarry spotting and basal stem lesions associated with Phytophthora disease, nor did their symptoms correspond with those of the “alder dieback” syndrome which has periodically occurred in Scotland during the last 30 years (Webber, Gibbs & Hendry, 2003) and which is characterised by rapid mortality of large portions of the branching structure. Instead, dieback was associated with extensive mortality of the root systems of the affected alders: no potential pathogens were isolated from the roots of such trees and this, combined with the lack of well-demarcated lesions in dying roots, the diffuse staining observed in the phloem / xylem of moribund and dead roots, and evidence for the existence of a permanently high but fluctuating water table in the areas where dieback was prevalent, provide strong evidence that waterlogging has been a major factor in the causation of dieback. This finding appears to be unusual, if not anomalous, on a number of different grounds:

1. That *Alnus glutinosa* is widely recognised as being highly tolerant of “waterlogging”.
2. That an aggressive water-borne pathogen (*Phytophthora alni*) is present immediately upstream of the area concerned but that trees do not appear to have been infected by it.
3. That water levels within the Mound Alderwoods must have increased within the last decade if conditions are now unsuitable for alders in areas where they established and grew satisfactorily in the past.

Knowledge of the exact tolerance of tree species to waterlogging or inundation remains fragmentary in spite of many observational and experimental studies because a number of different factors contribute to the effect of excess water on tree health including: the time at which inundation occurs, the frequency with which trees are inundated, the depth to which water submerges the trees, the duration of individual waterlogging events, and the quality of the water surrounding the roots of the trees during waterlogging (Glenz *et al*., 2006). Whilst alders may be tolerant of prolonged periods of submersion during dormancy and capable of surviving on permanently wet sites which are flushed with oxygenated water, it is equally true that they are intolerant of submersion during the growing season and of subjection to stagnant / anoxic conditions (Utschig, Esper & Pretzsch, 2001; Gorzelak, A., 2000). Thus, a diagnosis of waterlogging damage to alder is not unreasonable but is suggestive of elevated water levels occurring during the course of the growing season and of the roots being subjected to anoxic conditions for prolonged periods.

The apparent absence of *P. alni* from the region of the Mound Alderwoods south of the river Fleet might be accounted for in a number of different ways:

- The pathogen may only have arrived at the site relatively recently and therefore have had insufficient time to spread to the area concerned. This, however, would suggest that the initial dieback of trees to the north of the River Fleet noted in the mid-2000s might not have been attributable to Phytophthora disease.
- The conditions in the southern part of the site may be hostile to the pathogen and it has therefore been unable to establish within that area.
- The pathogen has infected trees to the south of the River Fleet but has not induced Phytophthora disease in its recognised form. For instance, it is feasible that *P. alni* could be attacking the fine roots of the trees without inducing lesions in the structural roots and stems. However, failure to isolate *P. alni* from the soil associated with dieback-affected trees in the south of the site casts some doubt on the likelihood of this possibility.

There is no direct evidence for an increase in water levels within the Mound Alderwoods over the last decade because, as noted earlier, there is no water gauging station either at the Mound itself or elsewhere within the Fleet catchment. Analysis of historic meteorological data for the site provided no indication that there had been a short-term increase in precipitation or extreme rainfall events in the recent past. However, the evidence which was gathered in relation to management of the Mound Alderwoods site indicates that there was a significant change in the policy with regard to alleviation of site flooding in the early 2000s. Prior to 2001 the Mound sluices were operated by a keeper who opened them in anticipation of spates in the Fleet catchment with the aim of preventing flooding both of the Mound Alderwoods and of upstream areas. This arrangement changed when BEAR Scotland assumed responsibility for management of the sluices in 2001, and guidance was later issued to landowners on the procedure which should be followed to arrange for the sluice gates to be opened after flooding of the adjacent land had occurred. This change in itself could have been expected to give rise to more frequent inundation of the Mound Alderwoods but the evidence further suggests that requests for opening of the sluice gates have rarely, if ever, been received by the companies responsible for their operation (initially BEAR Scotland and currently Scotland Transerv). Thus, it seems reasonable to conclude that both the frequency and the length of time for which the Mound Alderwoods site is inundated at times of flooding will have increased since 2001.

If the inferences which are drawn above are correct, then decline of the alders within the Mound Alderwoods is likely to have begun in the early to mid 2000s, rather than the mid to late 2000s when defoliation and dieback of the trees was first recorded. The dendrochronological studies reported here suggest that this may well be the case, with declines in the radial growth of trees at all of the locations investigated having occurred in the early 2000s, even in areas where dieback is currently absent. However, two lines of evidence from the dendrochronology appear to conflict with this interpretation:

- Firstly that the ash trees near plot FAH and adjacent to alders displaying a decline in growth rate showed no similar reduction in their growth. Waterlogging might have been expected to affect the growth of ash at least as severely as that of alder if inundation was the cause of the decline.
- Secondly, that a decline in the growth of the alders in plot FAC was apparent in the 1990s. If inundation has become an issue only since the early 2000s, then it cannot have been the cause of such a decline.

The roots of ash tend to occupy the soil horizons above the level of the mean summer water table (Ellenberg & Strutt, 2009) and thus are likely to be inundated for shorter periods than the deeper-penetrating roots of alder during transient flooding events. Nevertheless, the presence of aerenchyma in alder roots and other adaptations of the species to growth in wet habitats suggest that it is unlikely to be markedly less able than ash to contend with such conditions. As noted above, however, the likelihood of inundation having an adverse effect upon trees depends upon the time at which flooding occurs, with damage being most likely to arise when they are physiologically active. Flooding during periods when alder is physiologically active but ash is dormant (late spring and late autumn) could therefore account for the differences in their growth responses noted above.

The reduction in ring width and ring width index which occurred during the mid-1990s in plot FAC (Figure 2) had stabilised and to some extent been reversed by the late 1990s. The decline in growth rate of the same trees in the early to mid 2000s can therefore be interpreted as a separate event which may well have been brought about by a different cause. The fact that a previous decline of unknown cause occurred does not affect the weight of evidence indicating that waterlogging has been a significant factor in bringing about the current deterioration in the condition of alders.

The defoliation of alders which occurred in the Mound Alderwoods in the mid to late 2000s may have been triggered by stress to the trees induced by waterlogging and will undoubtedly have contributed to the rapidity of their decline by reducing the reserves which would have been available to them for production of recovery growth in the form of new roots and foliage-bearing shoots. However, the continued poor growth of trees which currently possess well-foliated crowns and display few signs of dieback provides a further line of evidence indicating that defoliation has not been a primary factor in the causation of dieback and decline.

4.2 Prognosis for alders affected by dieback

Phytophthora disease of alders is often lethal and extensive monitoring of diseased populations of trees carried out in England and Wales between 1994 and 2003 has indicated that an increase of approximately 1% per annum in the incidence of diseased and dead trees can be expected under average conditions in the south of Britain (Webber, Gibbs & Hendry, 2004). Information on the distribution and impact of Phytophthora disease in Scotland is extremely limited but the rate of disease development recorded in a small number of riparian plots monitored between 1998 and 2002 was less than 0.5% per annum and apparent recovery of some trees from infection was noted (Hendry, unpublished). However, *P. alni* lesions on the stems of infected trees within the Mound Alderwoods were sufficiently well-developed to cause crown thinning and dieback and it is unlikely that alders in this condition will survive.

Since *Phytophthora alni* is a water-borne pathogen, inundation of diseased trees favours its dissemination both locally and also more widely, if there is a current of water in which zoospores of the fungus may be washed downstream. It is therefore inevitable that the pathogen will spread from the areas of the Mound Alderwoods in which it was detected during the current investigations or possibly from a source further up the Fleet catchment, if it has not done so already. The chance of rapid spread of the disease is likely to be reduced if the area is flooded less frequently, to less depth and for a shorter duration than appears to have been the case in recent years, but such a change in conditions would prolong and not prevent the process of dissemination. Attempts to eliminate Phytophthora disease from a site through the felling or winching out of infected trees is not recommended because such operations cannot be conducted in a sufficiently comprehensive way to be effective. The disturbance created by this activity, including bringing machinery on site, may even spread the disease by allowing infective spores and fragments of the fungus from diseased trees or soil to come into contact with healthy trees.

Predicting the likely course of development of the dieback associated with waterlogging in the Mound Alderwoods is problematic because root mortality cannot easily be visualised and quantified. In areas where such dieback is currently evident, mortality of the branching systems of trees has been ongoing for over 5 years and a state of equilibrium in which the demands of the diminishing crowns of the alders are being met by their curtailed rooting systems does not yet appear to have been reached. This suggests that, unless a change in site conditions occurs in the short term, trees in the lowest lying areas such as the Confluence condition plot / FAC dendrochronology plot are likely to die back completely. It also appears unlikely that an improvement in the health of dieback-affected trees in slightly more elevated areas (such as at point 4, Figure 2) will occur if unfavourable site conditions persist, and further deterioration in their condition is possible. It is not possible to predict whether alders which have displayed a decline in growth since the early 2000s but currently show few signs of dieback are likely to deteriorate in condition: this would require knowledge of the present degree of root mortality in such trees and the establishment of a root mortality threshold beyond which dieback would be likely to occur. As suggested in relation to Phytophthora disease above, a regime in which the woodland is flooded less frequently, to less depth and for a shorter duration offers the best prospect for reversing the decline of trees which display dieback associated with waterlogging, and of preventing the deterioration of trees which are currently healthy.

4.3 Site history

Ideally, a detailed history of the Mound Alderwoods would be available to provide unequivocal evidence of past site conditions and management practices. In the absence of such a history, the information presented in section 3.4 was compiled in order to place the current decline of alders in context and to identify changes in the nature and management of the site which might have had a bearing upon that decline. The change in management of the sluices at the Mound over the last decade and the likely effect of that change has already been considered above. Since future management of the site could be informed by other aspects of the fragmentary history presented however, they will be considered briefly below.

It is noteworthy that tree cover did not develop over most of the area now occupied by the Mound Alderwoods until between 30 and 60 years after the completion of the Mound barrage in 1816. It is possible that this apparent delay in colonisation by trees was a product of the 1831 flood, which might have removed any developing woodland present at that time, but it appears more likely that enhanced drainage of the site as a result of installation of additional sluices around 1835 together with subsequent ground works including the digging of drainage channels played an important role in this change. Indications of a more widespread cover of both birch and conifers (presumably Scots pine) in 1873 than would be possible under present site conditions, tends to support this interpretation. The presence of a sluice at the junction of the main drain in the southern half of the site at the point where it was connected to the River Carnaig suggests that water flow within, as well as out of, the site was being managed at that time. The timeframe of 1830-1870 for initial colonisation of the site corresponds with the results of the dendrochronological studies carried out during this investigation.

Evidence of active management of the site extending into the late 1800s / early 1900s is provided by the development of an almost pure stand of Scots pine at the southern tip of the woodland during this period. This change indicates the maintenance of drier site conditions (in this part of the woodland) than currently exist and the appearance of rides between regular blocks of trees provide evidence of active husbandry. It is possible that the felling of these trees, which was reportedly carried out in the 1950s, led to natural wetting of the ground in the immediate vicinity; it is also possible that the drainage system in the area was affected during the operation. The dendrochronology results indicate that recruitment of alders in the western part of this area occurred as a single event in the late 1950s, and match exactly with the reported history.
Comparatively little information on the Mound Alderwoods during the first half of the 20th century was uncovered during the review, and the dendrochronological study suggests that

much of the current alder population was recruited during this period. Further work to provide a more complete understanding of the history of the site during the last 100 years would undoubtedly be worthwhile. A source of information which would be particularly worthy of further attention in this regard is the extensive collection of Sutherland Estate Papers deposited with the National Library of Scotland during the course of the last decade.

5 CONCLUSIONS

In light of the evidence presented above in relation to the causes of the current dieback of alders within the Mound Alderwoods SAC, a number of actions and further lines of enquiry are suggested:

- Serious consideration should be given to reinstatement of a policy for operation of the sluices at the Mound barrage which prevents, rather than reacts to, the flooding of the site. This is the main mechanism by which the reduction in flooding frequency, extent and duration recommended to address the problems of both Phytophthora disease and dieback associated with waterlogging might be achieved.

- In association with this, a mechanism for monitoring the water level at one or more locations within the Mound Alderwoods area would be advantageous.

- Monitoring of the condition of alders at various locations throughout the woodland should be undertaken in order to detect future changes in the extent, nature and severity of health problems in the trees.

- A thorough review of site history including management would be of benefit both in terms of understanding the development of the woodland at the Mound and in formulating current and future decisions in relation to site management. Such a review could usefully consider the factors associated with successful regeneration of alder in the past and those which may have prevented it in recent decades.

- Further information on the development of Phytophthora disease in Scotland is needed to better quantify the risk which it poses to alders both within the Mound Alderwoods and more widely. Research in this area should be encouraged.

- With respect to the Mound area in particular, a survey of alders higher in the Fleet catchment, to determine whether they are the likely source of the disease in the Mound Alderwoods, should be considered

- Selective baiting for *Phytophthora alni* within the woodland itself, to gain a better understanding of the disease risk in areas where the pathogen appears to be absent, should also be considered.

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7 APPENDICES

7.1 Correlations between tree growth and climatic variables (figures in red illustrate significant correlations).

		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Aug	May-June	MJJA	pMay_Dec
FAH temperature	period	correlations																								
	1914 - 2006	0.22	0.17	0.18	0.32	0.39	0.34	0.11	0.28	-0.01	0.00	0.03	0.19	0.24	0.27	0.21	0.21	0.38	0.25	0.08	0.27	-0.03	0.35	0.30	0.42	0.43
	1914 - 1944	0.11	0.04	0.35	0.37	0.54	0.46	-0.10	0.20	0.03	-0.10	-0.04	-0.08	0.30	0.16	0.32	0.12	0.49	0.21	0.02	-0.02	-0.09	0.24	0.27	0.41	0.48
	1945 - 1975	0.15	-0.04	-0.17	0.23	0.12	-0.03	0.08	0.39	0.15	-0.03	0.11	0.09	0.24	0.10	-0.17	0.31	0.12	-0.06	-0.02	0.41	-0.07	0.22	-0.03	0.16	0.21
	1976 - 2006	0.30	0.21	-0.01	0.18	0.30	0.39	0.00	0.21	-0.07	0.23	0.19	0.61	0.15	0.33	0.08	-0.03	0.36	0.23	-0.13	0.31	0.15	0.42	0.27	0.30	0.27
FAC temperature	period	correlations																								
	1934 - 2006	-0.12	0.20	0.03	0.19	0.09	-0.12	-0.22	0.10	0.06	-0.04	-0.05	-0.01	-0.04	0.05	-0.20	0.10	-0.14	-0.32	-0.16	0.02	0.12	-0.08	-0.09	-0.07	0.09
	1934 - 1944	-0.33	0.16	0.25	-0.28	-0.25	0.20	-0.43	-0.24	-0.03	-0.47	-0.71	-0.19	0.04	0.21	0.25	-0.14	-0.33	-0.36	0.37	-0.16	0.22	-0.51	0.25	0.05	-0.16
	1945 - 1975	0.07	0.01	-0.22	0.22	0.15	-0.17	-0.30	0.25	0.24	0.06	-0.05	-0.04	-0.03	-0.21	-0.56	0.07	-0.21	-0.29	-0.19	0.36	0.34	-0.22	-0.51	-0.37	0.08
	1976 - 2006	-0.28	0.37	0.02	0.03	-0.21	-0.37	-0.02	-0.15	-0.09	-0.08	-0.17	0.08	-0.19	0.05	-0.29	-0.17	-0.48	-0.58	-0.12	-0.41	-0.10	-0.26	-0.17	-0.38	-0.12
FAB temperature	period	correlations																								
	1961 - 2006	-0.28	0.05	-0.19	0.07	-0.02	0.07	-0.08	0.01	0.02	0.18	0.02	0.08	0.02	0.27	-0.16	-0.04	0.19	-0.15	-0.22	0.06	0.13	0.13	0.08	0.11	-0.02
	1961 - 1975	-0.53	-0.28	-0.19	0.28	0.25	-0.09	-0.15	0.09	0.57	0.36	-0.15	-0.34	0.11	0.07	-0.13	0.22	0.44	-0.17	-0.11	0.25	0.67	0.11	-0.05	0.33	0.24
	1976 - 2006	-0.16	0.23	-0.19	0.00	-0.11	0.13	-0.05	-0.02	-0.24	0.12	0.11	0.32	-0.01	0.38	-0.18	-0.15	0.09	-0.14	-0.27	0.00	-0.13	0.15	0.12	0.05	-0.10
FAP temperature	period	correlations																								
	1914 - 2006	0.07	0.25	0.16	0.20	0.24	0.23	0.08	0.12	0.00	0.07	0.08	0.21	0.07	0.32	0.20	0.14	0.33	0.10	0.10	0.10	-0.17	0.34	0.33	0.39	0.31
	1914 - 1944	0.13	0.31	0.45	0.31	0.44	0.36	0.05	0.10	0.11	0.04	0.19	0.26	0.08	0.22	0.40	0.18	0.39	0.25	0.21	0.09	-0.09	0.44	0.35	0.45	0.56
	1945 - 1975	0.19	-0.07	0.06	0.09	0.01	0.05	0.17	0.15	-0.01	0.08	-0.05	-0.07	-0.03	0.09	0.26	0.25	0.28	0.05	0.22	-0.13	-0.18	0.17	0.23	0.36	0.12
	1976 - 2006	-0.14	0.26	-0.24	0.03	0.07	0.11	-0.03	0.03	-0.06	0.15	0.12	0.35	0.04	0.51	-0.15	-0.09	0.25	-0.19	-0.13	0.09	-0.22	0.25	0.22	0.20	0.03
FAH Precipitation	period	correlations																								
	1914 - 2006	0.12	0.12	0.25	0.07	-0.02	-0.09	0.18	0.03	0.15	0.26	0.39	0.20	0.16	0.03	0.12	-0.02	0.07	0.01	0.10	0.07	0.20	0.40	0.11	0.09	0.20
	1914 - 1944	0.09	-0.22	0.10	0.29	0.10	-0.32	0.44	0.00	-0.23	0.15	0.21	0.18	0.01	-0.31	-0.02	0.23	0.14	-0.21	0.22	0.21	-0.04	0.36	-0.20	0.15	0.15
	1945 - 1975	-0.21	-0.30	-0.14	-0.06	-0.21	-0.35	0.05	-0.29	0.01	0.13	0.02	-0.05	-0.03	-0.38	-0.42	-0.03	0.13	-0.13	-0.18	-0.43	0.04	-0.16	-0.55	-0.31	-0.36
	1976 - 2006	0.11	0.40	0.13	0.22	-0.26	-0.20	-0.02	-0.12	-0.05	0.08	0.46	-0.09	0.21	0.24	0.04	-0.12	-0.19	-0.10	-0.06	-0.12	-0.01	0.23	0.20	-0.05	-0.04
FAC precipitation	period	correlations																								
	1934 - 2006	-0.08	-0.26	-0.21	0.06	-0.10	0.06	0.08	-0.04	-0.07	-0.02	-0.03	0.08	0.01	-0.13	-0.05	0.18	0.01	-0.01	-0.04	0.00	-0.01	0.03	-0.13	0.03	-0.12
	1934 - 1944	-0.07	-0.15	-0.64	0.20	0.33	-0.38	-0.38	0.25	0.45	-0.49	-0.20	-0.16	-0.14	0.37	-0.27	0.15	0.12	0.07	0.31	0.30	0.37	-0.36	0.01	0.33	0.02
	1945 - 1975	-0.06	-0.16	-0.32	-0.05	-0.30	0.27	-0.03	0.02	0.03	-0.15	-0.17	-0.28	0.00	-0.20	-0.14	0.26	-0.07	-0.11	-0.28	0.02	0.06	-0.22	-0.24	-0.06	-0.15
	1976 - 2006	-0.25	-0.34	0.14	-0.16	0.09	-0.05	-0.05	-0.20	-0.17	-0.14	-0.12	0.17	0.05	-0.09	0.27	0.10	0.31	-0.18	-0.47	-0.19	-0.01	0.18	0.12	0.29	-0.25
FAB Precipitation	period	correlations																								
	1961 - 2006	-0.09	0.24	0.01	0.12	-0.15	-0.07	0.11	0.07	0.09	0.00	0.17	0.04	0.03	0.00	-0.01	0.03	0.03	-0.01	-0.10	0.01	-0.09	0.11	0.00	0.03	0.13
	1961 - 1975	0.02	0.49	-0.08	-0.08	-0.26	0.01	0.15	0.60	0.24	0.30	-0.33	-0.11	0.28	0.15	-0.37	-0.02	-0.09	0.12	-0.17	0.27	-0.36	-0.09	-0.18	-0.23	0.37
	1976 - 2006	-0.13	0.11	0.06	0.21	-0.12	-0.09	0.10	-0.14	-0.01	-0.11	0.36	0.13	-0.05	-0.06	0.19	0.05	0.08	-0.04	-0.08	-0.09	0.09	0.21	0.09	0.12	0.00
FAP precipitation	period	correlations																								
	1914 - 2006	0.06	-0.07	0.17	0.05	0.00	-0.06	0.24	-0.10	0.04	0.14	0.29	0.10	-0.04	-0.16	0.08	0.09	0.12	0.05	-0.05	-0.04	-0.07	0.23	-0.05	0.09	0.08
	1914 - 1944	0.14	-0.30	0.11	0.13	-0.10	-0.19	0.26	-0.24	-0.31	0.15	-0.02	0.02	-0.09	-0.25	-0.04	0.32	0.04	-0.05	0.00	-0.14	-0.25	0.18	-0.18	0.18	-0.15
	1945 - 1975	-0.05	-0.03	0.10	-0.11	0.03	-0.28	0.15	-0.27	0.04	0.45	0.02	-0.06	0.37	-0.31	-0.30	-0.04	0.34	0.21	-0.37	0.06	-0.19	0.14	-0.42	-0.10	-0.10
	1976 - 2006	-0.06	-0.07	0.06	0.15	0.00	-0.06	0.23	-0.08	0.05	-0.13	0.48	0.02	-0.25	-0.19	0.14	-0.04	0.04	-0.04	-0.10	-0.13	-0.16	0.05	-0.04	-0.02	0.08

7.2 Extracts from the reports of the Commissioners for Highland Roads & Bridges / Commissioners for Repair of Roads and Bridges in Scotland relating to the construction and subsequent maintenance of the Fleet Mound

In establishing the site history of the Mound Alderwoods above, reference has been made to the reports to Parliament produced by the Commissioners for Highland Roads & Bridges (later the Commissioners for Repair of Roads and Bridges in Scotland) between 1813 and 1861. Whilst these sources are detailed in the References for the report, they are not widely available and extracts relating to the Fleet Mound are therefore reproduced here for the sake of convenience.

7.2.1 1813 report of the Commissioners for Highland Roads & Bridges

"FLEET MOUND. – It will not have escaped notice in the description of the last-mentioned road, that it is very inconveniently interrupted by a Ferry which crosses the entrance of a small Estuary North of the Dornoch Frith (sic), commonly called The Water of Fleet, from a River of that name which falls into it. The Little Ferry (as it is called with reference to the larger Ferry at Tain) is about Four Miles below the Head of the Estuary; but at Three Miles above the Ferry a situation has been found suitable for a Mound or Embankment; and this has been proposed to us as a cheap mode of superseding the necessity of this Ferry, which is the only one remaining to interrupt the Road from Edinburgh by Sterling to Thurso, when the Lovat Bridge over the Beauley River shall have been finished.

Thus the object is confessedly important, and had it been proposed as part of the Skibo Road, probably no hesitation had been experienced. In the existing state of things, we could not help reflecting that a certain portion of the Skibo Road already made would be rendered very nearly useless, and that we should not be justified in affording aid a second time to the same object though in an improved form.

In this difficulty we found no better expedient than to order an Estimate to be made of the Expence of the proposed work; and having deducted from it the expence incurred in the corresponding part of the Skibo Road, to consider the remaining Sum as that which was to be provided for. In diminution of this it was not forgotten that the intended Piers at the Little Ferry would become unnecessary, from whence would result a Saving of Thirteen Hundred Pounds, or full enough to make the new Road from the West side of the Little Ferry to the New Mound. On the East side between the Water of Fleet and Golspie, a new arrangement of the Farms had produced a considerable part of the desired Road almost in perfect form, so that if the unmade part of this piece of Road could be provided for by the Heritors of Sutherland, the discussion with regard to us stood upon the same ground as if the Mound had been proposed as part of the Skibo Road.

The estimated Expence of the Mound, and of the Bridge included as part of it, was Eight Thousand Four Hundred Pounds, a less Sum than had been paid for some of the large Bridges erected under our care; and in diminution of this Sum it appeared that an incidental benefit would arise from the Mound, in as much as it would defend about a Hundred Acres of cultivated Land from then effects of the Tide, and inclose about Four Hundred Acres of Sand in a situation where by the deposition of Mud, it might in process of time become valuable.

These advantages were scarcely susceptible of exact valuation, but being on the Sutherland Estate of the Marquis of Stafford, he made no objection to considering the contingent benefit as equal to a Thousand Pounds, at which our surveyor had valued it, and this notwithstanding the burden of making and maintaining Sluices to regulate the Water in a proper manner.

Thus the Expence of the Mound and Roads being lowered to Seven Thousand Four Hundred Pounds, we have reason to hope that the Contributors will themselves contract for finishing the whole work with the utmost expedition, and we are confident that the Benefit which will accrue to the East Coast of Sutherland, and the whole of Caithness, will be deemed fully commensurate with the expenditure thus to be incurred by ourselves and the Contributors in equal Moieties, they moreover engaging to finish the Road North of the Mound to Golspie at the expence of a Thousand Pounds."

7.2.2 1815 report of the Commissioners for Highland Roads & Bridges

"FLEET ROADS AND MOUND. – In our last Report to Parliament we explained at some length an arrangement which had been made for avoiding the Little Ferry, by a large deviation from the Line of the Skibo Road. Three Miles and a half of new Road are necessary for this purpose on each side of Strath-Fleet, and this has been completed in the Two last Seasons. Access is thus obtained to the more difficult operation about to be undertaken in constructing a Mound and Bridge across the Estuary. The Mound will be nearly One Thousand Yards in length, comprising a Bridge of Five Arches, fitted with Valve Sluices, by means of which a space of about Four Hundred Acres, at present inundated by the Tide as well a occasionally by Land Floods, will effectually be drained. The Contractors are not without hope of finishing the whole in the present Season; and although We hardly think such dispatch practicable, We are well assured that very prudent degree of exertion will be made, Earl Gower himself having lent his Name to the Contract. It is observable, that by means of this Mound, a communication will be perfected to the remotest part of Scotland, without the necessity of submitting to the Inconvenience of a single Ferry; those of Dunkeld, Beauley, Conan, and the Mickle Ferry of the Dornoch Frith (sic), having been already superseded by means of the aid afforded under the Highland Road and Bridge Act."

7.2.3 1817 report of the Commissioners for Highland Roads & Bridges

"FLEET MOUND. – The expectation of the Contractors that the Fleet Mound might be closed during the year 1815 was not realized, but they completed the Bridge of Five Arches, and ceased working on the Embankment in the Month of October, reserving themselves for the next Spring, at which time the work was resumed with redoubled energy; insomuch that in the beginning of June last the East and West Banks were advanced within Forty Yards of each other, and an attempt was made to close the interval. The first attempt did not succeed, and the materials were displaced by the Tide, but no one was discouraged, the want of arrangement among the Workmen being the only cause of failure; and on the 18th June the Breach was effectually stopped, and has since stood firm without leakage or other imperfection. This great Embankment is nearly a Thousand Yards in length, and towards the East-end its Base is Sixty Yards wide, its height is Twenty-three feet; and we hope that the ground thus gained from the Sea will become as valuable as has reasonably been expected.

Since June last the Road-way and facing of the Embankment have nearly been accomplished, and we have been solicited to take the work off the hands of the Contractors, they paying us the valued amount of the deficiencies; but it would be an unnecessary deviation from our practice to undertake party of a Contract in that manner without urgent necessity.

Mr Telford was on the spot in September last, and recommended an Estimate to be made of the Expense of a Row of Piles above the Bridge, and Gratings in the Arches, to defend the Sluices from injury by the Ice, which is brought down the River Fleet in great quantity after sudden Thaws."

7.2.4 1821 report of the Commissioners for Highland Roads & Bridges

"FLEET MOUND. – This great work seems to have been first projected by the Marquis of Stafford, or rather by Earl Gower, who cultivates an experimental Farm on the shore of Strath-Fleet. This Strath, or Valley, extends far up the Country, and into a District so rugged and mountainous that no practicable pass could be discovered; that through Strath-Carnoc being at such elevation as to be liable to obstruction from Snow during the Winter Months. The difficulty appeared to be insuperable, and what had been accomplished by the Bridges of Dunkeld, Lovat, Conan, and Bonar, was likely to fall short of the great object of establishing a communication, unbroken by Ferries, to the extreme North of Scotland.

The Marquis of Stafford offered to contribute One Thousand Pounds beyond the Moiety of the estimated expense of the Mound, in consideration of the contingent benefit derivable to his property from shutting out the Sea (which covered about Four Hundred Acres above the proposed site of the Mound), and to expend Two Hundred Pounds on the Sluices. With such encouragement, we did not hesitate at adopting the only practicable mode of carrying a Road across Strath-Fleet. The Embankment or Mound is of the most solid kind, to the extent of nearly One Thousand Yards in length, and the Road-way upon it is defended from the Surge and Spray of the Sea by a low Parapet Wall.

At the East end of the Mound are placed the Four Arches with their Sluices, by which the Water of Fleet, and occasional land floods pass to the Sea at Low-Water; but the Sluices being each Twelve Feet wide, they cannot be commanded without Machinery, which has therefore been provided and affixed.

Several Acres of Land, immediately above the Bridge, are always under water; but towards the upper end of the Strath, and the Western side of it, wherever any water descends from the side of the hills, a considerable degree of vegetation has begun to appear, and annually increases. The Arches required greater solidity of foundation that was provided by the original Estimate, and afterwards Rock Cutting was found necessary to admit the current of water to run direct upon the Sluices, which are now defended by a Row of Piles against large masses of floating Ice.

Additional Estimates to the amount of £855 were undertaken by the Contractors, besides which the Marquis of Stafford indemnified their loss on the original Contract to the amount of £644 and built a cottage for the use of the Flood Gate Keeper, at the expense of £78. Altogether, the entire expense of the Fleet Mound and of the Roads of approach to it, cannot have been less than Twelve Thousand Five Hundred Pounds, of which the Public paid no more than Four Thousand Seven Hundred Pounds."

7.2.5 1832 report of the Commissioners for Repair of Roads and Bridges in Scotland

"In the month of December, a great flood in the Uplands of Sutherland raised the water in Strath-Fleet, (an expanse of many miles in extent) to within 18 inches of the summit of the Mound by which it is retained. A strong Westerly wind produced a swell against the upper slope of the Mound, which being unprotected by pitching at the level which the water had attained, was considerably injured. The flood continued three days, during which time the danger of a breach over the top (which would probably have involved the entire destruction of this magnificent Work) was most imminent. Measures will be adopted forthwith to prevent the recurrence of such risk. Injuries of less consequence were at the same time sustained in Ross-shire, a little to the Southward of this District."

7.2.6 1835 report of the Commissioners for Repair of Roads and Bridges in Scotland

"In the County of Sutherland the two additional Arches at the Fleet Mound, with the corresponding Sluices and Machinery, have been completed in the most substantial manner, and abundant Waterway is now afforded for the passage of the highest Floods."

7.2.7 1857 report of the Commissioners for Repair of Roads and Bridges in Scotland

"The sluices of the Fleet Mound have this year been attended with little or no expense. The dwelling-house of the sluice-keeper, however, had fallen so much into decay that, with the approval of the Duke of Sutherland's Commissioner, I considered it advisable to build another cottage of a neat and substantial character, which has been done in a satisfactory manner, at an expense of 173*l*.15*s*.9*d*."

7.2.8 1861 report of the Commissioners for Repair of Roads and Bridges in Scotland

"Some repairs are necessary, in the course of this season, at the Fleet Mound; and a new arrangement will have to be made in regard to the Sluice Keeper, who has charge of the machinery and works at this place, the present Keeper being wholly incapacitated from old age. I shall communicate with Mr Loch, the Duke of Sutherland's Commissioner, on the subject, as serious damage might occur by any neglect in opening or shutting the sluices while the river is in flood."

7.3 Maps and assessment sheets for condition monitoring plots established during the course of fieldwork

7.3.1 Confluence plot assessment sheets and map

Alder Dieback Survey Assessment Sheet

Location: Mound alderwoods confluence plot

National Grid Reference: NH760992

Date: 300811

Sheet: 01

Stool data; Number & condition of stems by size classes: <7cm, 7-15cm, 15-30cm, >30cm

1 Stool number	2 Distance fm RB (m)	3 Dominance	4 Crown Contacts	5 Height (m)	6 Crown width (m)	7 Crown density (%)	8 Fruiting	9	10 All conditions	11	12 Healthy	13 Symptomatic	14 Dead	15	16 Healthy	17 Symptomatic	18 Dead	19	20 Healthy	21 Symptomatic	22 Dead	23
1	-	2	2	-	8	20	C					1				3						
2	-	2	3	-	8	15	A		2	LD		1				2				1		
3	-	2	4	-	4	5	S		3	LD		1				2						
4	-	3	3	-	3	5	A					4	4	LD								
5	-	3	4	-	4	5	A					5	2	RD								
6	-	2	3	-	8	10	A									2						
7	-	3	2	-	3	5	C									1	1	RD			1	RD
8	-	2	3	-	5	5	C		2	DB		3	1	LD						1		
9	-	1	3	-	4	5	C									1						
10	-	2	3	-	4	0	C						2	RD			1	RD				
11	-	2	3	-	4	5	C					7										
12	-	2	3	-	10	5	M										2	LD+R		2		
13	-	2	1	-	8	5	M					2				3						
14	-	2	2	-	5	5	C		1	LD		3				1						
15	-			-					3	LD			5	LD								
16	-		3	-	4	5	M					6				1						
17	-	2	2	-	3	0	C					1	4	1LD/3RD								
18	-	2	2	-	6	10	S					4				1	1	LD				
19	-	2	2	-	5	5	A					4					1	RD				
20	-	2	2	-	10	20	A									2				1		
21	-	2	2	-	7	5	A					3				1						
22	-			-					5	LD												
23	-	2	2	-	6	5	A		2	A						4	1	RD				
24	-	2	2	-	5	5	S		1	A		6										
25	-	3	2	-	4	5	C					5										

Number of stems / severity of symptoms by class: 7-15cm, 15-30cm, >30cm

1 Stool number	24 Leaf symptoms	25 Number / Severity	26 Twig dieback	27 Branch dieback	28 Stem dieback	29	30 Leaf symptoms	31 Number / Severity	32 Twig dieback	33 Branch dieback	34 Stem dieback	35	36 Leaf symptoms	37 Number / Severity	38 Twig dieback	39 Branch dieback	40 Stem dieback	41	42 Fungal fruiting?	43 Stem epicormics	44 Branch epicormics	45	Comments
1	SY	T	A	C	N		SY	T	C	S	N								N	M			
2	SY	T	A	A	N		A	T	A	A	C		SY	T	M	S	N		N	M			
3	SY	T	T	A	N		SY	T	A	A	N								N	M			
4	SY	T	A	A	S														N	M			
5	SY	T	A	A	M														N	C			
6							SY	T	A	C	N								N	M			Most foliage on epicormics
7							SY	T	C	C	N								N	M			
8	SY	T	C	M	N								SY	T	A	C	N		N	M			
9							SY	T	A	C	N								N	M			
10																			IR	N			A few shoots at base of larg
11	SY	T	A	A	N														N	C			
12													SY	A	A	C	N		N	M			
13	SY	T	A	A	N		SY	T	A	A	N								N	C			
14	SY	T	A	A	M		SY	A	A	C	M								N	C			
15																			IR	-			
16	SY	T	A	A	N		SY	T	A	A	N								N	C			
17	A	T	T	T	A														IR	S			
18	SY	T	M	M	N		SY	M	A	A	N								N	M			
19	SY	T	A	A	S														IR	C			
20							SY	T	M	S	N		SY	T	M	S	N		N	C			
21	SY	T	A	A	N		SY	A	A	A	N								N	C			
22																			N	-			
23							SY	T	A	A	N								N	C			
24	SY	T	A	C	N														N	M			
25	SY	T	C	C	N														N	C			

Alder Dieback Survey Assessment Sheet

Location: Mound alderwoods confluence plot | National Grid Reference: N H 7 6 0 9 9 2 | Date: 3 0 0 8 1 1 | Sheet: 0 2

Stool data (columns 1–9); Number & condition of stems by size classes: <7cm, 7-15cm, 15-30cm, >30cm (columns 10–22); Number of stems / severity of symptoms by class: 7-15cm, 15-30cm, >30cm (columns 23–41)

	1 Stool number	2 Distance fm RB (m)	3 Dominance	4 Crown Contacts	5 Height (m)	6 Crown width (m)	7 Crown density (%)	8 Fruiting	9	10 All conditions	11	12 Healthy	13 Symptomatic	14 Dead	15	16 Healthy	17 Symptomatic	18 Dead	19	20 Healthy	21 Symptomatic	22 Dead	23	24 Leaf symptoms	25 Number / Severity	26 Twig dieback	27 Branch dieback	28 Stem dieback	29	30 Leaf symptoms	31 Number / Severity	32 Twig dieback	33 Branch dieback	34 Stem dieback	35	36 Leaf symptoms	37 Number / Severity	38 Twig dieback	39 Branch dieback	40 Stem dieback	41	42 Fungal fruiting?	43 Stem epicormics	44 Branch epicormics	45	Comments
26	-	2	3	-	6	20	A					7				1	1	LD					SY	T	M	S	N		SY	T	S	S	N								N	M				
27	-	1	3	-	6	10	C		1	LD		2				1							SY	A	C	S	N		SY	A	C	S	N								N	M				
28	-	1	2	-	8	5	C					2				1				1			SY	A	C	S	N		SY	A	M	S	N		SY	T	A	C	S		N	M				
29	-	2	3	-									3	2LD/1RD																											IR	-				
30	-	2	3	-	5	5	A					3					1	RD					SY	T	A	A	M														N	M				
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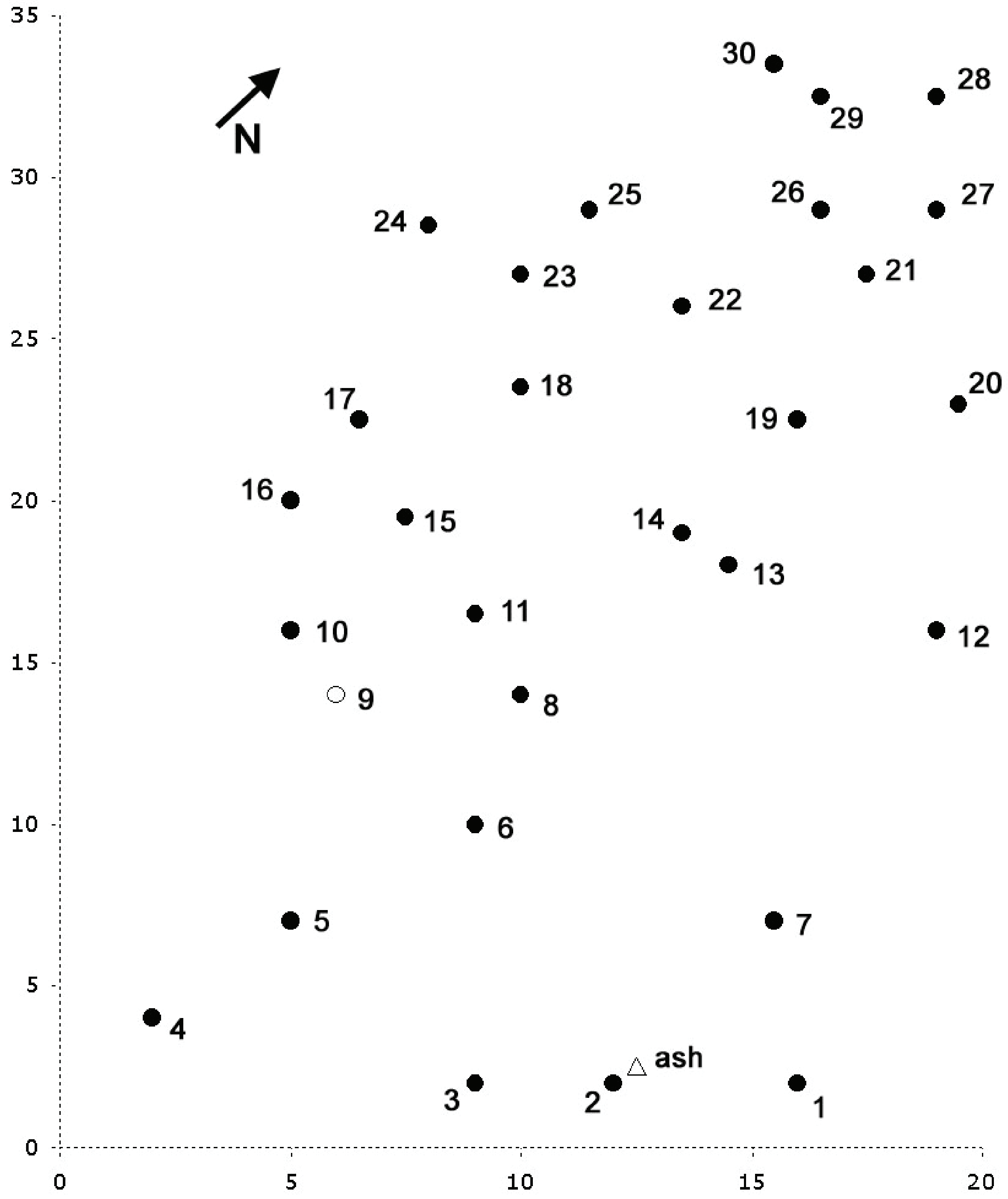
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7.3.2 Carnaig plot assessment sheets and map

Alder Dieback Survey Assessment Sheet

Location: Mound alderwoods, Carnaig plot

National Grid Reference: N H 7 5 9 9 8 9

Date: 3 1 0 8 1 1

Sheet: 0 1

Number & condition of stems by size classes: (columns 12–28) — Number of stems / severity of symptoms by class: (columns 30–45)

Stool data											<7cm				7-15cm				15-30cm				>30cm						7-15cm						15-30cm						>30cm				
1 Stool number	2 Distance fm RB (m)	3 Dominance	4 Crown Contacts	5 Height (m)	6 Crown width (m)	7 Crown density (%)	8 Fruiting	9	10 All conditions	11	12 Healthy	13 Symptomatic	14 Dead	15	16 Healthy	17 Symptomatic	18 Dead	19	20 Healthy	21 Symptomatic	22 Dead	23	24 Leaf symptoms	25 Number / Severity	26 Twig dieback	27 Branch dieback	28 Stem dieback	29	30 Leaf symptoms	31 Number / Severity	32 Twig dieback	33 Branch dieback	34 Stem dieback	35	36 Leaf symptoms	37 Number / Severity	38 Twig dieback	39 Branch dieback	40 Stem dieback	41	42 Fungal fruiting?	43 Stem epicormics	44 Branch epicormics	45	Comments
1	-	1	3	-	5	80	S												1																ID	M	N	N	N		N	S			
2	-	1	2	-	6	50	C													2															ID	M	M	S	N		N	S			
3	-	3	3	-	4	60	S												1																ID	M	S	N	N		N	S			
4	-	2	4	-	4	65	S								1														ID	M	N	N	N								N	S			
5	-	3	4	-	4	70	S								1														ID	S	N	N	N								N	S			
6	-	2	3	-	5	65	S								1														ID	S	N	N	N								N	S			
7	-	2	3	-	8	60	M						1	LD		2													ID	M	M	N	N								N	M			
8	-	2	4	-	6	65	M								2		1												ID	S	S	N	N								N	M			
9	-	2	4	-	6	65	S								1														ID	S	S	N	N								N	M/C			
10	-	2	4	-	5	60	M								2														ID	C	S	N	N								N	M			
11	-	2	4	-	4	75	M												1										ID	S	S	N	N								N	M			
12	-	2	4	-	5	75	S								1														ID	S	N	N	N								N	N			
13	-	1	4	-	10	60	S													1									ID	S	M	S	N								N	S			
14	-	2	4	-	8	60	S								1														ID	S	S	N	N								N	S			
15	-	3	3	-	6	45	S						1	LD						1									ID	S	S	S	N								N	M			Epicormics produced in reaction to ho
16	-	1	3	-	12	60	S						2	LD	1		1	LD	2										ID	S	N	N	N		ID	S	N	N	N		N	S			
17	-	2	4	-	3	50	S								1														ID	S	S	N	N								N	M			
18	-	1	3	-	6	60	S													1															ID	S	M	S	N		N	S			
19	-	2	4	-	5	50	S								1														ID	M	M	S	N								N	M			
20	-	2	4	-	6	50	S									2													ID	S	S	S	N								N	S			
21	-	2	4	-	6	60	S								1	1													ID	S	S	N	N								N	S			
22	-	2	4	-	8	65	S												1																ID	S	N	N	N		N	S			
23	-	2	4	-	6	70	S												1																ID	M	N	N	N		IR	S			IR fruiting on long-dead fork
24	-	3	3	-	5	45	S													1															ID	S	M	M	N		N	S			
25	-	3	4	-	4	50	C						3	LD		1													ID	S	N	N	N								N	M			

Alder Dieback Survey Assessment Sheet

Location: Mound alderwoods Carnaig plot

National Grid Reference: N H 7 5 9 9 8 9

Date: 3 1 0 8 1 1

Sheet: 0 2

Stool data (1–8) | Number & condition of stems by size classes: <7cm, 7-15cm, 15-30cm, >30cm | Number of stems / severity of symptoms by class: 7-15cm, 15-30cm, >30cm

	1 Stool number	2 Distance fm RB (m)	3 Dominance	4 Crown Contacts	5 Height (m)	6 Crown width (m)	7 Crown density (%)	8 Fruiting	9	10 All conditions	11	12 Healthy	13 Symptomatic	14 Dead	15	16 Healthy	17 Symptomatic	18 Dead	19	20 Healthy	21 Symptomatic	22 Dead	23	24 Leaf symptoms	25 Number / Severity	26 Twig dieback	27 Branch dieback	28 Stem dieback	29	30 Leaf symptoms	31 Number / Severity	32 Twig dieback	33 Branch dieback	34 Stem dieback	35	36 Leaf symptoms	37 Number / Severity	38 Twig dieback	39 Branch dieback	40 Stem dieback	41	42 Fungal fruiting?	43 Stem epicormics	44 Branch epicormics	45 Comments
26	-	2	2	-	8	60	S												1																ID	M	S	S	N		N	N			
27	-	2	2	-	6	50	S									3													ID	S	M	S	N								N	S			
28	-	2	3	-	6	65	M								2														ID	S	S	N	N								N	S			
29	-	2	4	-	4	70	S												1																ID	S	N	N	N		N	M			
30	-	1	4	-	12	60	S												2																ID	S	S	N	N		N	S			
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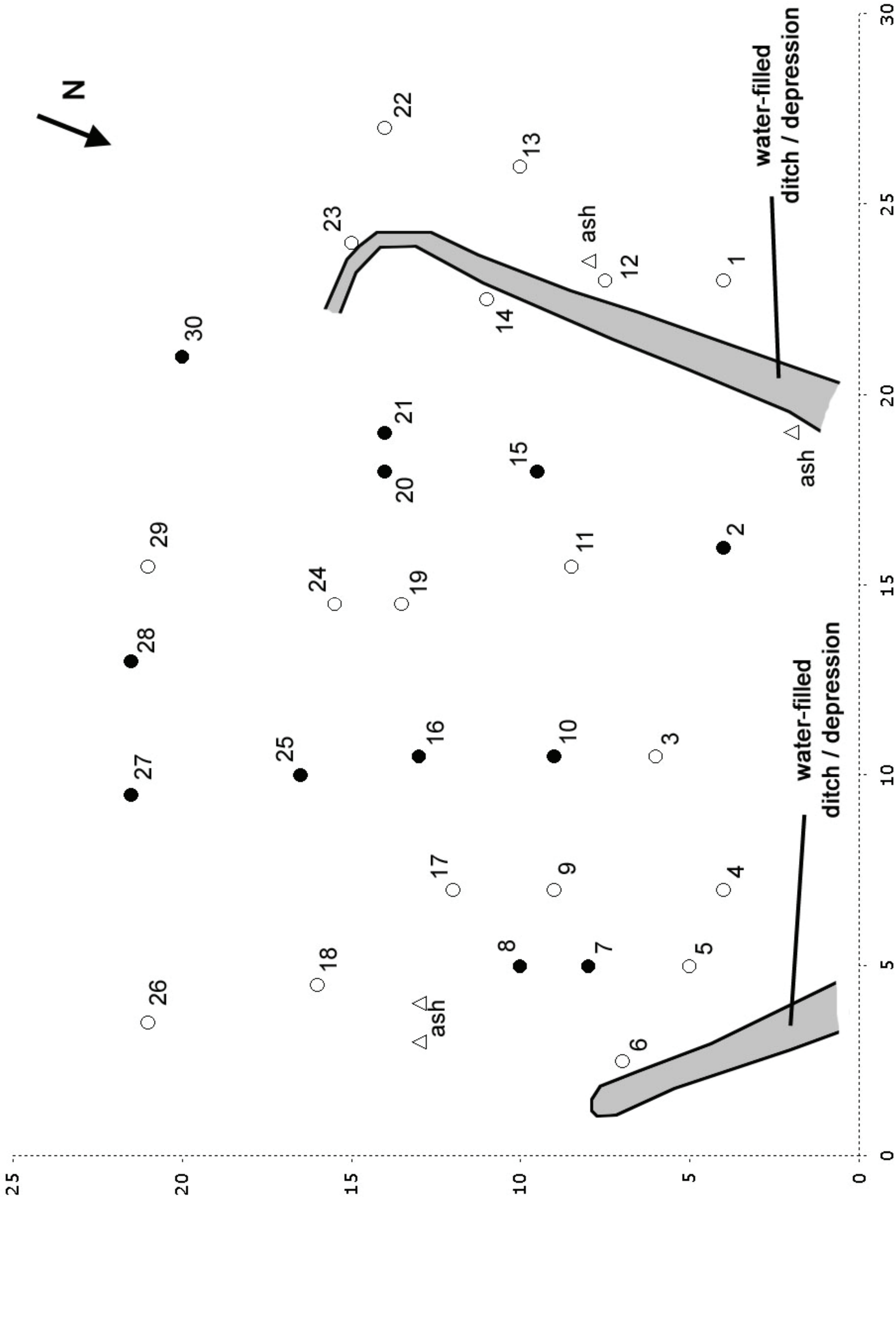

N
water-filled
ditch / depression
water-filled
ditch / depression
ash
ash
ash

7.3.3 Notes on interpretation of assessment sheets and maps

Maps:

- Axes shown on plot maps indicate distances in metres.
- Open circles represent maiden (single-stemmed) alders; filled circles represent alder stools (multi-stemmed); triangles indicate the positions of ash stems.
- Numbers shown against alder stems / stools correspond with the numbers employed in the assessment sheets.

Assessment sheets:

- Annotations by columns recording dead stems indicate age of mortality: RD = recently dead, LD = long dead
- Abbreviations used in “Leaf Symptoms” column are as follows: SY = small & yellow, ID = damaged by chewing insect.
- In columns recording the severity of symptoms, a 6-point scale is employed as follows:

Abbreviation	Meaning	Percentage of leaves / leaf area affected
N	none	0%
S	scarce	>0 and <10%
M	moderate	>10 and <30%
C	common	>30 and <60%
A	abundant	>60 and <100%
T	total	100%

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