The biology and non-chemical control of Bracken (*Pteridium aquilinum* (L.) Kuhn

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Bracken
(brake, brackenfern)
***Pteridium aquilinum* (L.) Kuhn.**
(*Pteris aquilinum, Eupteris aquilinum*)

Occurrence

Bracken is considered to be the most widespread vascular plant in the world (Hudson, 1987). In the UK it is found on damp soils, meadows and pastures up to 1,920 ft (Salisbury, 1961). In Wales, western and northern England and western Scotland it dominates large areas of land. Unusually for a fern, bracken is a very successful coloniser and is widespread on neutral to acid soils (ADAS, 1980). It is tolerant of a wide range of climatic conditions, is highly disease resistant and releases allelopathic compounds that inhibit the growth of other plants (Hudson, 1987). The vigorous growth and dense foliage shade out other vegetation (Pakeman & Marrs, 1993). In the Countryside Survey 1990, the total area of bracken in Britain was estimated to be 17,000 km^2 (Barr *et al.*, 1994). Of this, 28% was dense bracken on open land, 25% was scattered bracken on open land and 47% was bracken in woodland. The data indicated there had been a decrease of about 10% in the dense area of bracken between 1984 and 1990.

Originally a lowland and woodland plant it now infests many upland areas and has done so for over 150 years (Watt, 1954). In the 1800's sheep replaced cattle on much of the rough grazing, scattered rural populations were dispossessed and the bracken menace began with bracken being no longer made use of (Fenton, 1937). Bracken is less invasive when growing in woodland but following tree clearance it becomes much more vigorous. It was probably never more than a minor component of the woodland flora (Daniels, 1986). In woodland and in controlled conditions of shade, bracken plants have fewer fronds that are thinner and with a greater surface than those in the open. Bracken is often present in oakwoods on light non-calcareous soils (Tansley, 1949a). Deep shade restricts the vegetative spread but even under moderate shade it can become dominant. Bracken is less invasive when growing in woodland but following tree clearance the increased light level stimulates luxurious growth. The thick litter of fronds built up under bracken prevents woodland regeneration. Bracken is often found growing with bramble or creeping soft-grass (*Holcus mollis*).

Bracken is normally found on acid soils and is uncommon on calcareous land. It prefers well-drained sites as the young rhizomes cannot stand waterlogging and stops abruptly at the edge of marshy ground. Improved drainage on hill land has allowed bracken to colonize formerly wet sites. A dense litter builds up under bracken that prevents most other vegetation becoming established andmay even affect the bracken itself if the litter layer is too deep (Grime *et al.*, 1988). Bracken does not normally spread rapidly into heathland perhaps due to the compacted peat soil (Tansley, 1949b). However, where the soil is loose or disturbed the bracken will advance and out-compete the heathers. Bracken has spread into bent-fescue grassland severely reducing the grazing value (Tansley, 1949b).

Bracken is better protected from fire than most other species on moorland but it will not survive where late spring frosts regularly kill off the emerging fronds. The litter of dead fronds provides some protection against frost but the upper limit for bracken growth on hills is determined by the effect of frost and wind on the fronds. It does not succeed on exposed slopes due to wind damage. In coastal areas bracken fronds suffer salt damage during gales and this may lead to rotting of the rhizomes (Gillham, 1955).

Bracken is a very variable plant and is often divided into separate species, subspecies and varieties (Stace, 1997). There are reported to be 12 geographic varieties, ssp. *aquilinum* has eight of these and ssp. *caudatum* has four (Mitich, 1999). Plants within patches usually consist of several genetically distinct individuals (Pakeman & Marrs, 1993).

Bracken has spread into bent-fescue grassland severely reducing the grazing value (Tansley, 1949b). Bracken is poisonous to stock, the fronds being most toxic at the newly emerged 'crozier' stage (ADAS, 1983). The fronds become less toxic with age but fronds cut for animal bedding should have died back entirely. Bracken remains poisonous if cut green, dried and stacked (Forsyth, 1968). Fronds cut and cured with hay have caused poisoning in horses in winter when hay was the sole feed (Huffman & Couch, 1943). The rhizomes are also poisonous and are a potential hazard to pigs that may uproot them and to cattle when ploughing exposes the rhizomes. Bracken causes ulceration and blood loss in cattle, bright-blindness in sheep and a vitamin deficiency that in horses leads to 'staggers' (ADAS, 1980). Bracken is implicated as a human health hazard due to its suspected carcinogenic spores. It also provides a habitat favoured by sheep ticks that transmit Lyme disease. It has been considered of little conservation value in terms of wildlife because fewer birds breed in bracken and the abundance of invertebrates is lower (Hudson, 1987). However, there are associations between bracken growing with violets and some fritillary butterflies (Pakeman *et al.*, 2005). It is also the preferred habitat of the whinchat and nightjar. Glands at the base of the pinnae exude a substance attractive to ants (Mitich, 1999).

In the past, bracken was used for animal bedding and as a source of potash for glassmaking (Pakeman & Marrs, 1993). It has even been used to make a rather unpalatable silage and as a covering for potato clamps (Willis, 1954). Bracken that has been utilized for animal bedding can be used to produce FYM. The fronds themselves make a good compost of low pH that improves soil texture (MAFF, 1949). A mixture of bracken fronds, sheep's wool and manure has been composted to produce potting compost. Fronds are also a potential biofuel and the plant ash has a high pH and is rich in potash and other beneficial minerals (Donnelly *et al.*, 2002; Donnelly *et al.*, 2006; Davies, 2006). There have been suggestions that bracken could be harvested as a renewable energy source (Callaghan *et al.*, 1984; Hudson, 1987). A mulch of bracken fronds may have an allelopathic effect on the germination and growth of weeds. Extracts of bracken are thought to have anti-fungal and insect repellent properties and to kill aphids (Donnelly *et al.*, 2002). Bracken contains flavanoids that have antibiotic properties, and ecdysones that may have potential for insect deterrence.

Biology

Bracken is a perennial with an extensively branched rhizome system that constitutes a formidable reserve of growth potential (Pakeman & Marrs, 1993). There are two types of rhizome, long thick storage organs that branch and run deep underground but produce no fronds and short thinner, shallower rhizomes on each of which a single frond is borne each growing season. A dormant bud at the base of each frond gives the plant a potential replacement set of fronds (Mitich, 1999). On deep soils the rhizomes may extend to a depth of more than a metre. Elsewhere, a high proportion may be found in the top 23 cm of soil. Extension rhizomes that advance ahead of the main patch may grow one or more metres in a year (ADAS, 1980). Rhizomes grow particularly strongly in the autumn when large numbers of frond buds are initiated (Cody & Crompton, 1975).

Fronds generally emerge in May and arise singly from short lateral branches of the rhizome (ADAS, 1980). Fronds that develop early in the main flush of emergence become the fertile fronds. Those that expand later seldom develop mature sporangia. Spores ripen from July to August and are shed from August to October (Clapham *et al.*, 1987; Grime *et al.*, 1988). Bracken has relatively small spores for a fern (Conway, 1957). In optimum conditions spore output can be extremely high. It has been estimated that a single frond can produce 30 million spores. However, fertile frond numbers and hence spore production can vary from habitat to habitat, area to area and year to year. Fertility is reduced by shade in woodland habitats for example. Plants need to reach 3 to 4 years of age before fertile fronds are produced. Prior to this, most of the resources go into rhizome development. Periodic defoliation can limit spore production. Early defoliation in May has a limited effect but if this is repeated in June, fertile fronds are reduced by 85%. A further defoliation in July will eliminate them completely. Late frosts can destroy emerging fronds while wet conditions in August and September prevent spore dispersal. Any delay in dispersal may not allow spores time to germinate and establish young sporophytes before the winter.

Under controlled conditions, bracken spores readily develop but the sexual phase of reproduction is delicate and requires the right amount of moisture (Salisbury, 1962). Sporeling plants have been found in cracks and crevices in rocks and brickwork (Conway, 1953). A large number of prothalli and young sporelings were found in the rubble heaps of bomb damaged towns in 1943-45. The prothalli often suffer fungal damage and the bomb-sites may have provided disease-free sites. The prothalli and sporelings are susceptible to prolonged periods of frost.

Spores are likely to fall on agricultural soil with a high level of mineral nutrients. Nitrogen, potassium, phosphorous and calcium have been shown to be important in the establishment of young bracken plants (Conway & Stevens, 1957). In studies on agar and a sand/peat compost increased levels of the different nutrients tended to slow spore germination but at later growth stages nitrogen and potassium stimulated development. When sporelings with 4-5 fronds unfurling were transferred to garden beds the addition of lime, potash, phosphate and nitrogen fertilizer all increased the growth of the young bracken plants. Nitrogen in the form of ammonium salts had a greater effect than nitrates. Higher mineral nutrition markedly increased frond initiation, secondary shoot numbers and the production of a network of branched rhizomes. There was a greater incidence of dormant stem apices at the end of the growing season that could potentially increase the ability of plants to survive extreme cold. Frond density is influenced by the level of oxygen diffusion in the soil (Anderson, 1961). The plant can control this itself to some extent by the disruption of the soil caused by rhizome growth.

A large number of rhizome buds occur per unit area on a favourable soil (Watt, 1950). Frond differentiation takes place mainly in summer but only a proportion of the buds become new fronds. The same shoots do not differentiate new fronds every year and some may remain dormant for several years. Not all the differentiated fronds emerge and the developed fronds are just a fraction of the potential fronds. New fronds can differentiate while a current frond is intact but if the current frond is killed or injured by frost or mechanical damage the new frond grows faster. The older rhizomes at the centre of an infestation are nearer the soil surface because of the litter layer that builds up under the fronds than the newer rhizomes around the edge (Watt, 1954). However, the apices of the advancing rhizomes around the margins are more susceptible to frost because the litter layer is thinner and there is less frost protection. Also the soil warms up sooner without the insulating layer of litter and the fronds emerge earlier in the year. These fronds of deeper origin are longer than those of shallower origin and in March the apices are nearer the soil surface and more susceptible to frost (Watt, 1950). Depending on the severity of the winter, apices at depths of 1.9 to 7.1 cm may be killed. A severe winter frost can kill a high proportion of fronds and rhizome apices near the soil surface unless a blanket of snow is present to protect the bracken. Severe winter frosts kill the apices of the rhizomes whereas hard spring frosts damage the emergent fronds. Dormant buds soon replace the damaged fronds (Salisbury, 1962).

Young plants produce a relatively higher number of foliar organs than older plants whose whole rate of growth slows down as the plant matures (Conway & Stephens, 1957). Three phases of bracken growth are recognised; a pioneer phase, a mature stage and a degenerate phase (Anderson, 1961). The length of the frond bearing rhizomes decreases as plants behind the leading edge of the patch reach maturity.

Persistence and Spread

Spores are probably only important in colonizing new sites. Spores may persist in the soil and can remain viable for up to 10 years (Grime *et al.,* 1988). However, culture studies on agar and in soil, and short-term burial studies suggest that there is considerable predation of the spores by insects (Conway, 1953). The development of new plants from spores requires constant moisture and freedom from frost, conditions that less likely to be met outside of woodland. Spores are not therefore a major source of spread (ADAS, 1980). However, in a rich soil a young plant could develop very rapidly (Conway & Stephens, 1957).

Woodland clearance begun in prehistoric times and continued to the present day has contributed to the spread of bracken (Hudson, 1987). The increased incidence of burning and higher grazing pressure has prevented tree regeneration allowing bracken to invade the disturbed areas. In competition with gorse (*Ulex europaeus*) and other scrub vegetation, bracken is favoured by burning (Salisbury, 1929). Heavy grazing reduced the competitive ability of palatable grasses allowing bracken to spread further putting greater grazing pressure on the remaining grassed areas. A fall in the management of uplands and reduced use of bracken foliage for stock bedding has allowed expansion to continue unchecked.

At all localities in Britain where the rate of encroachment has been monitored, bracken is spreading not receding (Hudson, 1987). The overall rate of encroachment has been estimated as 2.8% per annum. However there is not a constant advance and sometimes the margins may retreat (Watt, 1954). After severe winter frosts that kill the main rhizome apices, there may be a substantial check to the rate of advance. Biochemical tests used to determine the extent of individual plants of bracken have indicated a maximum dimension of 390 m (Sheffield *et al.*, 1989). This may signify plants of considerable antiquity. Individual rhizomes have a limited lifespan of just a few years but the rhizome system is persistent (Pakeman & Marrs, 1993). Individual clones of bracken in Finland have been dated back to the middle of the Iron Age (Sarukhán, 1974).

Separate plants may arise where there is fragmentation of rhizomes due to rotting or mechanical damage (Cody & Crompton, 1975). In pot culture, the capacity for regeneration appears to be unaffected by the type of rhizome planted and the presence or absence of apical buds (Daniels, 1985).

Management

Bruising the unfurling bracken fronds with a 'bracken bruiser' is one control technique (Soil Association 2002). The damage causes the stems to bleed and this weakens them. It is best carried out after late May, preferably in late June/early July but before August. Crushing with a roller twice a year for 3 years is also said to be successful. The 'Bracken o'Bliterator' fits onto an ATV and is a simple heavy roller fitted with 10 crushing bars. The standard machine has a working width of 1.5 m but larger versions are available. A bracken roller can be towed by tractor, quad bike or horse. In ancient times it was thought that the sap trickling from the damaged fronds killed the roots (Smith & Secoy, 1976). Care should be taken to avoid harm to late-nesting birds in July.

Pulling of bracken is effective but is little used. The 'Eco-puller' has been developed to mechanically remove perennial weeds such as common ragwort (*Senecio jacobaea*) and creeping thistle (*Cirsium arvense*) from grassland (Soil Association, 2002). It has a working width of 1.5m and a ground speed of 5 kph at 540 rpm. The weed gripping height is adjustable but weeds should be at least 30 cm tall. It can be used in bracken once the croziers lose brittleness and before the fronds open fully.

Cutting is less effective than crushing because the cut surfaces heal more rapidly. A range of different cutting dates and frequencies has been suggested. According to early publications of good husbandry it was thought best to cut bracken at all times of the year (Mitich, 1999). For best results cutting should commence in early June/mid-July with a second cut in late July/August after fronds regrow and a final cut in September before the frosts (Crofts & Jefferson, 1999). The timings should aim to cut the bracken at 4 to 6-week intervals through the growing season. Nevertheless, cutting the fronds before August is the most common form of control in organic systems (Donnelly, 2004). Cutting should be done twice each year in late May and early August. Up to the time when the bracken reaches full height but before the fronds fully unfurl, the plant is nourished by food reserves in the rhizomes. Cutting at this time exhausts the reserves and repeated cutting in successive years weakens the plant progressively (MAFF, 1949). Bracken reaches the most vulnerable stage around the beginning of June. A second cut should be made in mid-July or as soon as the fronds are sufficiently high to make cutting practicable (Willis, 1954). Cutting twice each year should be repeated for at least three years but complete clearance may take seven years. A third cut each year reduces the time taken to clear an area but may not be feasible to carry out. Morse & Palmer (1925) suggest cutting at monthly intervals from June to September. A dressing of lime is said to be beneficial after cutting. Cutting and slashing machines are equally effective initially but bruising machines are less so as fronds became smaller. All the machines have some difficulty reaching the fronds as the bracken regrowth becomes shorter.

In an experiment to study the effect of frond removal, bracken plants were cut in late-May or late-May and late-June, or late-May and late-June and late-July but after the first year there was no difference in bracken growth compared with uncut plants (Stephens, 1953). After 3 years of treatment, frond number and height were reduced and the effect increased with cutting frequency. However, there was little extra advantage in making 3 cuts compared with 2. The number of rhizome tips remaining alive was lower after the cutting treatments and a higher proportion were non-dormant. Dormant rhizomes are more likely to survive cutting treatments because their reserves remain intact.

In a 3-year study of bracken management across a range of climatic zones in Great Britain, while some treatments gave a consistent effect at all sites others did not (Paterson *et al.,* 1997b). Treatments included cutting once a year, cutting twice a year, and applying asulam once at 4.4 kg a.i./ha alone, preceded by a single cut or followed by a single cut of the bracken. The bracken was cut with a brushcutter and the fronds left where they fell. Cutting once yearly was the least effective management regime and the one that exhibited the greatest variation between sites. A single application of asulam had the greatest effect on frond biomass and density but cutting twice a year reduced rhizome biomass more. It was concluded that the choice of treatment should depend on the management objective and the option for treatment continuity.

Frond treatments will affect bracken cover in the current season but it is the effect on frond development in future years that is important (Conway, 1960). In a study of the effectiveness of cutting over a ten-year period, cutting once annually reduced bracken fronds by 70%, cutting twice reduced them by over 90% but did not eradicate them completely (Lowday & Marrs, 1992a). The fronds were cut in mid June and late July when cut twice, and in July if cut just once. Establishing a good vegetation cover helped to suppress any regrowth but a sown cover was better that relying on natural regeneration. Extrapolation of the results suggested that cutting for a further 8-10 years would be needed to eradicate bracken completely (Marrs *et al.,* 1993). If cutting ceased before eradication, the bracken gradually recovered. The above ground frond biomass was closely related to the rhizome biomass. Cutting back the bracken fronds twice a year for 10 years reduced the frond bearing rhizomes to 2-4% and storage rhizomes to 8-11% of the untreated (Marrs *et al.*, 1992). The treatment also reduced the litter layer. Cutting once a year was less effective. Where the cutting treatments ceased after 6 years the rhizomes exhibited considerable recovery.

With an annual cutting treatment, the biomass of bracken fronds has been found to increase relative to an untreated area in the year following the initial cutting treatment (Marrs *et al.*, 1998a). In subsequent years there was a gradual reduction. Cutting bracken once a year for 18 years reduced frond biomass to 6% of untreated levels. Seeding with *Calluna vulgaris* had no consistent effect on the level of bracken control but there was a clear negative relationship between the biomass of bracken fronds and that of understorey heath vegetation. Where annual cutting ceased after 6 years frond biomass recovered rapidly to untreated levels after 4 years. The effect of cutting twice a year for 6 years persisted after treatment ceased and frond biomass remained depressed for at least 12 years. Although cutting twice a year was superior to a single annual cut when both treatments were applied continuously for 10-12 years, after 18 years the single cut was superior (Marrs *et al.* 1998b). Neither cutting treatment eradicated bracken completely after 18 years of application. After a continuous period of treatment the bracken seems to reach a new equilibrium at a lower level of biomass production. Cutting frequently, each time the fronds regrow, may diminish the plant more but is very labour intensive (Tansley, 1949b).

Ploughing in May, June or early July gives good control of bracken especially if crops such as potato, rape, turnip or oats are then grown (MAFF, 1949; ADAS, 1980). Cultivation in two successive years will eradicate bracken. If sown down immediately to grass there may be regrowth especially after winter ploughing when the rhizomes are dormant. Ploughing exposes the rhizomes to frost action that may give additional kill (The Southern Uplands Parnership, 2001). Cutting the fronds before ploughing stresses the rhizomes (Crofts & Jefferson, 1999). Ploughing in very hot weather increases the damage to the exposed shoots and rhizomes. Deep tine cultivations in 2 directions can give a measure of control without ploughing (Pakeman *et al.*, 2005). Regular cutting or further tillage will be required to prevent re-establishment.

The rhizomes may suffer greater frost damage if the protective litter layer is removed (Donnelly, 2004). However, burning off the litter puts valuable nutrients back into the soil and promotes subsequent bracken growth. The application of NPK fertilizers has been shown to give a general increase in frond numbers and rhizome extension (Daniels, 1986). On steep slopes where there is little underlying vegetation, burning off the bracken may result in soil erosion (The Southern Uplands Parnership, 2001). Deep tine cultivations will cause mechanical damage to the rhizomes and increase their exposure to frost or desiccation.

In the dormant season and during early frond growth restricted areas of bracken have been cleared through trampling by sheep or cattle (ADAS, 1983). This destroys the young shoots as they unfurl which together with the destruction of the litter layer tends to reduce subsequent bracken growth. Small patches of bracken can be controlled but not the expansion of large areas of bracken (Lake *et al.*, 2001). Cattle and ponies have a greater effect than sheep (Small *et al.*, 1999; Popay & Field, 1996). Winter feed can be used to attract stock onto the bracken area (Pakeman *et al.*, 2005). Poultry in moveable runs can be effective too. In areas with a deep soil, rooting out with pigs works well on small patches but stirs up the soil and destroys the vegetation cover. A narrative report of bracken clearance by pigs on the Isle of Islay states that the pigs are both effective and selective (Randall, 2006). In woodland, heather moorland and in open fields with unploughed bracken patches, the pigs uprooted the bracken rhizomes but left the heather and seedling trees largely undisturbed. The long term effect of pig clearance has yet to be determined. Other studies in Scotland are underway using wild boar to clear bracken and allow tree plantations to be established. Pigs can also be turned out onto land that has been ploughed to expose the rhizomes (Salisbury, 1961). An alternative food source needs to be available to avoid the animals eating only bracken (Willis, 1954). Grazing by sheep favours bracken and is thought by some to be responsible for the widespread increase in the weed (Tansley, 1949a). Although bracken is rarely grazed there may sometimes be damage (Fenton, 1940). Rabbit activity was greater where cutting treatments had been applied (Marrs *et al.*, 1998c).

It has been said that when bracken takes over grassland it may be best to just re-establish forest (Tansley, 1949b). The large-scale clearance of bracken on hill pasture is unrealistic without measures to improve the husbandry techniques that have allowed the problem to exist (Nicholson, 1960). In cleared areas, species need to be present or sown that can cover the ground quickly and prevent the bracken returning. Cock's-foot (*Dactylis glomerata*) and creeping softgrass (*Holcus mollis*) are two of the best grasses for this (Williams, 1976). The choice of species for re-instatement of the vegetation during and after bracken clearance depends on the situation (The Southern Uplands Parnership, 2001). The land may be seeded down to heather (*Calluna vulgaris*), to grass or woodland may be established from tree seedlings or saplings. Grazing will need to be restricted for several years to allow the vegetation to establish successfully. In uplands, mixed cattle and sheep grazing is said to encourage heather growth. Where heather and bracken patches occur adjacent to each other, either may advance into and replace the other (Watt, 1955). The balance of dominance depends on the growth phase of the heather and whether it has suffered damage from cutting, burning or rabbits. Bracken tends to advance on a continuous front while the heather infiltrates and develops behind the leading edge of the bracken where frond growth is less vigorous.

The litter layer limits the restoration of a heathland even when the bracken fronds are cut back or killed. Where bracken had been killed by applications of the herbicide asulam a number of different methods of litter reduction were compared on land that was seeded with locally collected seeds or left unsown (Lowday & Marrs, 1992b). The treatments included rotovating the litter into the mineral layer, burning the litter in situ or raking off the litter and removing it. All the treatments allowed faster restoration by sown species. Complete removal of the litter layer was best where the site was recolonized with heather (*Calluna*). Increased rain penetration and higher nutrient levels after bracken clearance can encourage colonization by unwelcome species. On a sown *Calluna* heath in Breckland over a 10-year period of bracken clearance by cutting once or twice a year, two clonal species sand sedge (*Carex arenaria*) and wood small-sedge (*Calamagrostis epigejos*), invaded in large patches where vegetation cover was poor (Marrs & Lowday, 1992). In a grass heath, the sown sheep's-fescue (*Festuca ovina*) became co-dominant with wavy hair-grass (*Deschampsia flexuosa*) which colonized naturally.

In long term studies on unmanaged heathland, there is a cycle where bracken invades grass heath, increases in density and then degrades to leave grass heath again (Marrs & Hicks, 1986). The bracken does not die out completely and may increase again at a later date. The bracken degeneration could be the result of a build up of frond litter.

Bracken management may stimulate regeneration as cutting will reduce the litter layer and also stimulates the production of new frond buds on the rhizomes.

A bracken growth model (BRACON) has been developed to predict bracken stand dynamics in relation to cutting and other control regimes (Paterson *et al.*, 1997a). The model provides a reasonable description of rhizome dynamics for individual treatments but tends to underestimate bracken resilience. However, the effect of climate fluctuations on frond biomass can distort the accuracy of any predictions. There are also effects due to the slope and aspect of a site that can limit the accuracy of any long-term predictions without further improvement of the model (Pottier *et al.*, 2005).

A review of the literature in 1967 gave an indication of the number of insect species known to attack bracken in Europe (Simmonds, 1967). The prospects for biological control of bracken with insects and mycoherbicides were later discussed by Burge *et al.*, 1988. Biological control has been tried with the caterpillars of two South African moths (*Conservula cinisigma* and *Panotima* sp.) (Fowler *et al*., 1989) but with little success (Pakeman & Marrs, 1993). The use of mycoherbicides has also been investigated (Munyaradzi *et al*., 1990). The fungal pathogens *Ascochyta pteridis* and *Phoma aquiline* cause curl-tip disease of bracken. Trial results so far indicate a need for adjuvants to ensure adequate uptake of the inoculum.

Where the fronds are cut as a crop, September onwards is the time for cutting if reserves in the rhizomes are not to be depleted (Donnelly, 2004). The fronds can be baled for storage. Cutting for animal bedding does little to reduce plant vigour as the fronds are dry when harvested (Tansley, 1949b).

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