FLF

Future Landscapes Forum

Position Statement on the problems Bracken causes in Great Britain and the demise of asulam

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WHO ARE WE?

The Future Landscapes Forum is a group of academics and practitioners with specialist knowledge of the management, ecology and functioning of semi-natural landscapes in the UK. Many of us have conducted key research and published a considerable body of recent peer-reviewed science and assessments on land management. Our shared views represent a collective body of knowledge on the current state-of-play with respect to Bracken (*Pteridium aquilinum* (L.) Kuhn) within the GB.

Why are we speaking out?

As a group of leading scientists and practitioners in upland management and socio-ecological impacts, we have growing concerns around the public and policy debate about managing bracken and the issues around the use of the herbicide asulam. Asulam is an herbicide used to control bracken and docks. It is usually marketed as the product Asulox, which contains 400 g/L of asulam as the sodium salt.

In 2011, as part of a review of all pesticides, the EU decided that the available evidence to support the safe use of asulam did not meet the criteria for registration under EU Regulation 1107/2009 (Anon, 2011). In the UK, the effect of this was that asulam was not authorised for use after a use-up period which expired at the end of 2012. However, Article 53 of Regulation 1107/2009 allows an annual Emergency Authorisation (EA) to be applied for in exceptional circumstances. The Bracken Control Group submitted successful UK-wide applications for the bracken control seasons in 2013-2022. In 2023, the EA was approved in England, but not in Northern Ireland, Scotland or Wales. In October 2023, for commercial reasons, the manufacturers announced they were stopping the research on asulam required to support the application for re-regulation and, as progress towards this was a prerequisite of a further EA approval, no EA application could be submitted for 2024. As asulam was the safest and most effective herbicide for controlling bracken and was approved for helicopter-based applications (needed for large areas, and places where there is no vehicle access, including steep slopes, and rocky / broken ground), its removal from the control options leaves a major gap.

For many years, the discussion about bracken has focussed on the use of asulam. A more rounded debate has been lacking about the threats posed by the plant and the other options to mitigate its dominance and contain or reduce the level of cover. The withdrawal of asulam has highlighted the lack of leadership about bracken in all parts of the UK and this needs to be rectified urgently. The Scottish Government commissioned a Rapid Evidence Review from the James Hutton Institute (Pakeman, 2023) which highlighted a number of knowledge gaps that should be addressed to allow decision making to be based on better evidence. Currently, the biggest knowledge gap is the area of bracken in the UK and whether or not this area is increasing, as landowners and managers believe it is.

We suggest this vacuum requires action from Defra, their constituent agencies and their equivalents across the UK. The drafting of preliminary Bracken Guidance is underway, but this is seen as a stop-gap, and it is understood that this guidance will be published without the benefit of any input from stakeholders. The proposed development of an UK Bracken Strategic Framework, which will follow the preliminary guidance, is also welcomed. However, this must include an opportunity for all stakeholders to contribute to the drafting and time must be allowed for an informed debate about the issues and a chance to agree on research priorities. It is also seen as important that the Framework allows for improvement of the Bracken Guidance so that it becomes something of value to practitioners and not just a means for regulatory control.

At first sight, bracken and its control appears to be a simple subject. However, it quickly gets complicated by the range of interest groups that are affected by it and the number of different specialisations that are required to develop an understanding of the issues and a response to them. Add to this a complete lack of recent discussion about the threats associated with bracken and how to mitigate them, and the subject expands to large proportions. Here, we summarize five main topics around current understanding on:

1. **What bracken is.**
2. **How much bracken is out there?**
3. **How is bracken cover likely to change with respect to changes in climate and other management factors?**
4. **What problems does bracken cause land managers?**
5. **How do we control bracken and restore other plant communities without asulam?**

This position statement offers a short summary of key peer-reviewed research findings, together with some work that is in progress. We have ensured that the evidence we refer to is based on sound science, any statements (or opinions) are substantiated by evidence wherever possible. We intend to invite all stakeholders involved in the policy formation and management of bracken landscapes to meet to discuss the evidence base and develop a consensual approach to the management of this important weed species with many impacts, for example, on grazing and biodiversity (e.g., Argenti *et al*., 2012) but also on soil chemistry (e.g., García-Jorgensen *et al*., 2021), carbon cycling and water quality (e.g., Aira *et al*., 2021).

A SUMMARY OF CURRENT EVIDENCE

What bracken is

Bracken is a fern and is one of the most successful plants in the world being present on all continents except Antarctica. It has several attributes that make it so successful, *inter alia*:

- It can produce large fronds in the Spring and Summer which form a canopy that shades out other species (Watt, 1945, 1947; Lowday *et al.*, 1992a; Pakeman *et al.*, 2000, Le Duc *et al.,* 2000).
- It has a large underground rhizome system that acts as a store of food and nutrients to fuel frond growth and provides protection from frost, fire and surface disturbance. There are also a large number of both active and dormant buds that form new fronds in subsequent years or if the current frond canopy is removed (Lowday *et al.*, 1992b; Le Duc *et al.*, 2003).
- Once the fronds die-back in autumn, the dead fronds add to the accumulated litter layer. This layer prevents other species from colonising (Watt, 1969, 1970).
- It contains a large number of secondary plant chemical compounds, some of which are carcinogenic, cytotoxic, mutagenic, tumorigenic and teratogenic *inter alia* (Evans 1976a, 1986; Santos *et al*. 1992; Cross *et al*. 1996; Ngumuo & Jones 1996; Simán *et al*. 2000) including sesquiterpenoids, ecdysones (moulting hormones of insects), cyanogenic glucosides, tannins and phenolic acids, which presumably act to provide anti-herbivore and anti-microbial defence (Cooper-Driver 1976; Cooper-Driver *et al.*, 1977; Evans 1976b; Castillo *et al.* 2000; O'Connor *et al.*, 2019) or allelopathy (Gliessman, 1976; Gliessman & Muller, 1978; den Ouden, 1995).

  The bracken variant found in the UK is usually *Pteridium aquilinum* subsp*. aquilinum; P. esculentum* is prevalent in the Southern hemisphere (Marrs & Watt, 2006).

How much bracken is out there and the measurement of change?

Assessing the amount

It might be expected that the amount of bracken present in the UK could be measured easily and such data would be readily available. Unfortunately, this is not the case. It might seem obvious to use some form of remote sensing imagery to count the large splodges of bracken green in the countryside. However, there are real technical difficulties in separating bracken as an unique entity from grasslands, and indeed since 2007 bracken has been lumped into grasslands within UK Land Use cover maps. Moreover, remote sensing is unable to estimate the entire land area covered by bracken, because:

1. Bracken often exists at differing frond densities in the open countryside, and whilst dense bracken can often be picked up by remote sensing, there are often many areas of sparse bracken which are nigh on impossible to assess at the moment. Sparse patches (patches with < 25% frond cover are often difficult to pick up; Pakeman *et al.*, 1996a).
2. Bracken grows under trees where it cannot be seen by aircraft or satellites because it is obscured by the overlying tree canopy. It is important to measure this bracken because if the trees are cut down the bracken area visible by remote sensing increases markedly, and quickly, and will clearly influence estimates of amount present and especially change between when sampled through time (Pakeman *et al.*, 1996a).
3. Bracken when growing in linear features (hedges, fence-lines, road and railway verges) is also difficult to spot; yet these can clearly act as a source for invading new land (Pakeman *et al.*, 1996a).
4. Bracken can grow in a series of growth-phases where frond density increases and then decreases in a cyclic manner before recovering (Watt, 1945, 1947, 1976; Marrs & Hicks, 1986). If this occurs, assessments of land infestation densities will alter through time, even though there is no effective change, and thus produce very uncertain and often incorrect measures of change.

First estimates of the bracken coverage of Great Britain were made through a combination of field observations and remote sensing for estimating bracken cover in Wales and then extrapolating these data to the GB-scale using a series of assumptions (Taylor, 1986). This produced an estimate of 4729 km^2. However, subsequent revision of the assumptions reduced this to 2360 km^2 (Taylor, 1990).

Thereafter, two approaches have been used to provide estimates of bracken coverage in Great Britain. The first used a field-based survey, i.e. the UK Countrywide Survey at 1 km^2 scale (the UK Countryside Survey), carried out using a stratified-random sampling based on land-cover classes (Barr *et al.*, 1990; Bunce *et al.*, 1991). Using this approach, estimates of bracken land cover of 2800±700, 4200±1200 and 3700±600 km^2 were achieved for 1978, 1984 and 1990 respectively, or 1.2%, 1.8% and 1.6% of the total area of Great Britain (Pakeman *et al.*, 1996a). Note, the very high standard errors attached to these estimates, ranging from 16.2-28.6% of the estimated amount. Thereafter, repeat surveys have concentrated on the Bracken Broad Habitat classes (defined as 95-100% bracken cover) and considerable fluctuations in amounts have been found between 1984 and 2007 with estimates of 4390 km^2 (1.9% land area), 2720 km^2 (1.2%), 3150 km^2 (1.3%) and 2600 km^2 (1.1%) in 1984, 1990, 1998 and 2007, respectively (Carey *et al*., 2008). Between 1998 and 2007, significant reductions were reported for Wales and GB overall; but Northern Ireland showed no change and Scotland showed a marginal increase of 0.1% (Carey *et al*., 2008). The Countryside Survey has not been run since 2007 and results from the new rolling program are not yet available.

The second approach using remote sensing (UK Land Cover Map) estimated 3603 km^2 for 1990. which was within the same general ranges of the land cover and broad habitat estimates produced by the subsequent UK Countryside Survey (Pakeman *et al*., 1996a). More recent attempts to map bracken within the Land Cover Map have emphasised some of the difficulties. For example, Fuller *et al*. (2002) highlighted the difficulty in obtaining even the minimum number of training areas for bracken, i.e. where the spectral data form areas with known bracken cover which is then used to provide data to classify the entire map. Because of this, estimates may be less reliable. Moreover, the dataset for the 2000 Land Cover Map adds that estimates may be unreliable because some of the imagery was taken before the bracken canopy got to full cover and there is a difficulty in assessing dissected bracken stands (Anon 2000). From 2007 onwards, essentially to maintain consistency, the bracken class has been incorporated into “acid grassland”: the authors note “*Bracken can be mapped using LCM2007 methods, but it depends on image timing, so for consistency it is assigned to “Acid Grassland”* (Morton *et al.,* 2014).

In 1990, additional information on bracken distribution was collected within the Countryside Survey. Here, for the first time, the total area of land infested with some bracken was estimated. In this survey, bracken was also counted in four classes, dense and sparse bracken in both the open and under woodland. Taken together this produced an estimate of 17072 km^2 (7.3% of GB), more than four times the estimate of the bracken land class or indeed the bracken broad habitat (Pakeman *et al.*, 1996a). In addition, there was 122,000 km of linear features containing *P. aquilinum* (Pakeman *et al.*, 1996a). Thus, simple assessments based on dense bracken in the open can hide a much wider potential problem of land which has some bracken present and, importantly, with the potential to expand.

Assessing change

If measuring the total amount of bracken in the UK is hard, it is even more difficult to measure change in status. Bracken can only colonise new land in two ways (Marrs & Watt, 2006), first by sexual reproduction via the spore-prothallus-fern pathway, and second by rhizome invasion. In the UK, most invasion\reinvasion of land is via rhizomes. The evidence for this is that: (a) spores are very rarely produced in most areas, and especially in the uplands, and (b) reports of colonization via the sexual pathway are almost non-existent. It must have happened in the past and may possibly occur occasionally via mast spore years when there is a very large spore production akin to the mast years of many tree species, e.g. Beech (*Fagus sylvatica*). However, for bracken it is currently rare. Therefore, most invasion must come via rhizome invasion. Invasion via rhizome extension is relatively slow, usually (ca. <1 m per year, Pakeman *et al.*, 2002) with a maximum recorded of 1.8 m per year (Marrs & Watt, 2006). If this is so, many rates of suggested increase in the literature are implausible and probably reflect mixing true colonization with changing frond densities associated with recovery from control treatment or cyclic growth phases.

Is bracken cover likely to change with respect to changes in climate and other management factors?

Extensive modelling of the responses of bracken to climate change in the mid-1990s (i.e., Pakeman & Marrs, 1996b) showed that the predicted changes in climate showed that bracken extent and cover was likely to increase in productivity and spread. Before the models were tested, the senior scientist (Professor R H Marrs) was in two minds as to whether bracken would react positively or negatively with respect to global warming. Whilst it was likely that bracken would increase productivity in summer this might have been offset by much greater rhizome respiration in warmer winters. However, this was not the case. In the end, one of the key model factors affecting bracken performance was the frost-free period (Pakeman & Marrs, 1996b). Bracken is very sensitive to frost and as the latest spring frosts become earlier and first autumn frosts become later the fronds can photosynthesise for longer (Braid, 1937, Lowday, 1983; Watt, 1954, 1964).

It should also be noted that bracken can act as a large store of carbon and other elements (Marrs et al., 2007; Rosenburgh et al., 2013), estimates of 0.5 Gt of carbon was estimated for the UK by Marrs et al., (2007), although the authors were aware that this was a first approximation.

The other factor that could increase bracken performance and presumably spread is a reduced grazing pressure associated with stock reductions through extensification or rewilding. In recent experiments where bracken control treatments have stopped, bracken recovery in plots where control success was good (but not great) was much faster where the vegetation was ungrazed compared to where sheep-grazing remained in place, even though at low densities. However, we don't have good evidence of the effects of grazing where control has not taken place.

What problems does bracken cause land managers?

There are a few places where *P. aquilinum*-dominated vegetation provides valuable habitat for species of conservation interest, often where the bracken canopy acts as a surrogate canopy for the food plants of butterflies, e.g. (STOG, 1988; Pakeman and Marrs, 1992; Bulman and Bourn*,* 2005). This is often where the bracken patch covers an area that was formerly woodland (Marrs & Watt, 2006). Bracken can also provide a habitat for many species of bird, notably the Whinchat (*Saxicola rubetra*), but a range of other species have been documented (reviewed Pakeman & Marrs 1992). It also provides a landscape feature, especially in autumn after the fronds turn brown (Pakeman & Marrs, 1992). However, a general review of the pros and cons of the bracken habitat showed that where it colonizes, the conservation value is generally reduced relative to the communities that it replaces (Pakeman and Marrs, 1992). Moreover, it was regarded as one of the four over-dominant native species that could be linked to reduced species diversity in British Broad-Leaved Woodland (Marrs *et al.*, 2011, 2013).

Elsewhere, bracken invasion causes problems for livestock-based, extensive agriculture, conservation, recreation, and game management (Pakeman and Marrs, 1992; Marrs and Watt, 2006). In 1988, bracken was shown to cost £8.8m to the agricultural economy in the Least Favoured Areas of England and Wales through reducing the amount of available grazing and increasing the costs of stock gathering and veterinary bills (Lawton and Varvarigos, 1989). It is poisonous to grazing animals causing *inter alia* Vitamin B1 deficiency in mono-gastric animals (Evans *et al.*, 1975, Evans, 1976b), and both gastric tract cancers and enzootic haematuria in other grazing livestock (Hirono, 1986; Xu, 1992). Correlative data has suggested that it may be implicated in some human cancers although causation is unproven (Wilson *et al.*, 1998; O'Connor *et al.*, 2019). Ptaquiloside, one of the carcinogens produced by *P. aquilinum*, has been detected in potable water supplies (Clauson-Kaas *et al.,* 2016; Vaidotas *et al*., 2022) and this is an obvious cause for concern. As yet, the spatial extent of such water contamination at the UK scale are lacking, especially in private wells.

Bracken-dominated vegetation can harbour ticks (Sheaves and Brown, 1995) with their associated diseases affecting both humans (Lymes disease, Tick-borne encephalitis) and animals (Louping Ill, other tick-borne diseases) Hudson *et al.* 1995; Marrs and Watt, 2006). Almost half of farmers surveyed in the LFA in England and Wales reported a bracken problem and 68% favoured a National Control Scheme (Varvarigos and Lawton, 1991).

How do we control bracken and restore other plant communities without the use of asulam?

There are essentially three ways of controlling bracken, by: (1) mechanical techniques (Milligan *et al*., 2016, 2018, i*nter alia*), (2) herbicidal approaches (Milligan *et al.,* 2016) or (3) biocontrol approaches (Lawton, 1988, 1990):

- **Mechanical control** can be done by cutting, pulling, bruising (variously termed breaking, rolling, crushing, bashing) and ploughing/discing/rotavating. Where the infestation is very small, control can be achieved by pulling the fronds out of the ground or cutting the fronds by hand (sickle, scythe or strimmer). Realistically, on any patch of reasonable size, cutting has to be done using a mechanical cutter (usually a flail or rotary one) and drawn behind an ATV or tractor. Where the ground is very steep in the uplands the use of standard agricultural powered machinery becomes difficult, indeed it is virtually impossible. However:
    - Small Alpine tractors are becoming more common. Their small size with a low centre of gravity and their ability to operate with dual wheels extends the capability of a tractor-drawn cutting and bruising equipment.
    - The recent introduction of self-powered Robocutter-type cutting equipment has helped to reduce the operators' risk as these machines are capable of operating on steep slopes beyond the capability of an ATV/tractor. However, they cannot operate on rocky or broken ground.

  Bruising is a traditional technique used in Britain up to just after the Second World War, before the advent of suitable cutting machines and effective herbicides (Braid, 1959). Today, there are a variety of designs of bruisers available, indeed pre-World War II almost every village blacksmith had a design of their own! Bruising involves running over the fronds with the bruise producing breaks/nicks along the frond rachis, damaging them, but not severing them (Braid, 1959). Modern bruising machinery is designed to be drawn by ATVs or tractors but some can also be drawn by heavy horse. The advantage of bruising over cutting is that it can be applied much faster than cutting especially on rocky, steep or uneven ground (Lewis *et al.,* 1997). However, in the only experiment that compared bruising with cutting and asulam within a statistically-valid experimental design bruising fared very badly, being only marginally better than the untreated control whereas cutting and bruising gave excellent results (Milligan *et al*., 2016; Marrs *et al*., 2023).

  Ploughing/discing was deemed a useful method pre-war; here the aim is to break up the rhizomes into fragments, get as many near the surface as possible where winter frosts will kill them. Thereafter, the aim was to establish a crop, usually grass. However, this approach depends on having flattish land that is suitable for ploughing (summarized Braid, 1959). The only recent attempt to use ploughing as part of a control strategy was by Snow and Marrs (1997) who first removed the surface layer, then replicated plots were set up that were ploughed and disced or left unploughed and then within these plots three bracken control treatments were implemented. Ploughing produced a better initial impact compared to no ploughing, but this effect did not last. Rotavating is a more modern technique and this has the same terrain limitations as discing.

- **Herbicidal control** in Great Britain is now restricted to the use of glyphosate, given that asulam is no longer an option. Asulam had several advantages over glyphosate. First it is relatively selective; it does control bracken although it affects other ferns and produces minor effects on few other species (Marrs, 1985) although damage to *Rumex* spp., bryophytes, some fine-leaved grasses and algae have been reported (Byrne, 2003; Rowntree *et al.,* 2003; Måren *et al.,* 2008). Second, asulam was one of the few herbicides that was licensed in the UK for aerial application by helicopter (Pakeman *et al.*, 2005), which made it ideal for applications on steep slopes and on rocky terrain which limits the use of ground operations. Neither of these benefits apply to glyphosate; it is non-selective and affects almost all other species which makes it far less suitable for use in situations where the protection of underlying or adjacent species is essential. It is also not licensed for aerial applications. Whilst it may be possible to apply glyphosate by ground sprayers in some situations where there is no threat to underlying plant species, most glyphosate applications to control bracken are likely to be done using weed wipers. Weed wipers achieve herbicide selectivity by physical means. The boom, which has herbicide-laden brushes, pads or ropes along its length, is set at a height where the herbicide is only applied to the taller bracken, with the smaller plants below the bracken canopy being left untouched. Weed wiping is restricted in the same way as cutting, as the wipers are drawn behind an ATV or tractor.

  Attempts have been made to assess the use of potential replacement herbicides for asulam (Brown 2022), with amidsulfuron showing some promise (Cooke *et al.*, 2022). Although amisulfuron did control bracken it produced less long-term control than asulam and it appeared to affect more non-target species (Cooke *et al.*, 2022). It too is not licensed for aerial spraying in the UK.

- **Biocontrol methods** that have been suggested as a potential control strategy include the use of insects (the moths *Conservula cinisigma* and *Panotima* sp. near *angularis*, (Lawton *et al.* 1986; Lawton 1988, 1990) or the fungus *Ascochyta pteridis* as a myco-herbicide (Burge & Irvine 1985; Burge *et al.* 1986; Womack *et al.* 1995), maybe even in tandem. These approaches have not been developed beyond the laboratory and would require a lot of test and development before large-scale use in the UK.

  Two other biocontrol approaches are possible, the first is to accept that bracken is a woodland species and plant trees within the bracken in the hope that they will overtop the bracken canopy in time and eventually reduce the bracken coverage by shading. This is possible, but to our knowledge tree planting as a bracken control measure has never been tested experimentally [but see Newman (2024) who explores this issue]. The second, is through the use of grazing animals, cattle, horses, large, wether sheep or pigs. Observations in the literature (Braid, 1959) and anecdotally by UK upland managers suggest that appropriate heavy stocking rates might help reduce bracken over a long time period, primarily by trampling. The use of virtual fencing approaches to confine animals to specified areas is a possibility (Anon, 2023; Waterhouse, 2023). However, irrespective of how grazing animals are used, we must be cognisant of the impact that the health of these animals can be very heavily impacted by ingesting bracken. Indeed, Braid (1959) states in reported discussions of livestock management and bracken "*it has been hinted that the death rate amongst livestock through eating bracken was very high*". There is increasing concern amongst veterinary surgeons about direct poisoning of livestock from bracken ingestion. Apart from the ethical issues of using, or indeed encouraging, livestock to graze a poisonous plant, it will be important that managers using this approach. and their vets are aware of likely symptoms, and thereafter, know how to treat them.

Lessons learned during the asulam era

The one major new fact to emerge from studies carried out during the asulam era is that, irrespective of the method used to control bracken, it takes time and continued, multiple treatments to guarantee a long-lasting effect. Asulam gave at best good control for a short- to medium-term – up to 10 years where it has been most effective. Where it was especially good was where after the first asulam application was applied it was followed up with annual spot-treatments. Where this was done excellent results have been obtained (Robinson, 2000; Milligan *et al*. 2018; Marrs *et al*., 2023). Long-term studies with other herbicides have not been done but the general principles derived for asulam are likely to hold (Robinson, 2000; Milligan *et al*., 2018; Akpinar *et al*., 2013; Marrs *et al*., 2023), i.e., either repeat treatments are necessary or continued spot applications of the herbicide to emergent fronds are likely to be required.

The follow-up to the primary treatment does not need to use the same control method. Good results may be obtained if livestock, especially cattle, are grazed on the area after primary treatment has taken place.

Where mechanical treatment by cutting has been applied for a long time, good results in terms of bracken control have also been achieved but this has required between a minimum of 8 years cutting twice/thrice per year (Milligan *et al*., 2018; Marrs *et al*., 2023) and 14-25 years of cutting twice per annum under experimental conditions (Milligan *et al*., 2018; Marrs *et al*., 1998;Akpinar *et al*., 2013; Marrs *et al*., 2023). In a recent unpublished study, cutting once per year for 20 years gave reasonable results but when the treatments were stopped bracken recovery was much faster than comparable plots given two cuts or extended asulam treatments (R.H. Marrs, unpub.).

Therefore, where cutting can be used to control bracken it must be viewed as a long-term strategy and where good results have been obtained, continued monitoring of the developing vegetation is needed with new treatments applied if (or rather when!) the bracken starts to increase again. Essentially an adaptive management strategy is needed combined with long-term monitoring.

CONCLUSIONS

- Bracken is a major weed problem in Great Britain, and not just in the uplands. Whilst there are some situations where bracken is beneficial and an essential component of our native ecosystems, in most places it reduces species diversity and causes problems for other land uses including agriculture, forestry, sporting and recreation.
- Bracken is full of secondary plant compounds some of which are carcinogenic or mutagenic. It is toxic to grazing livestock if eaten. There are correlative links with the incidence of some human cancers. It produces a carcinogenic compound which has been detected in potable water supplies. The bracken habitat harbours ticks which act as a reservoir for Lyme disease and other tick-borne diseases.
- Bracken also negatively affects water quality and likely also soil carbon stocks by affecting soil chemistry and carbon turnover.
- Until 2022/3 bracken could be controlled using the herbicide asulam. In 2011 this herbicide was not approved for further use in Europe, but it has remained available in the UK until recently via an annual emergency authorisation. In 2023, for commercial reasons, the manufacturers withdrew it from use in Britain and, hence, it is no longer available.
- One issue associated with asulam use was that derived chemicals, purporting to be produced from asulam degradation, were occasionally found in reservoirs at amounts that appeared to be difficult to reconcile with the amount of recent asulam sprayed on the surrounding catchments.
- In spite of its widespread distribution throughout Great Britain, accurate knowledge of the amount of bracken-infested land is weak, at best we have good estimates of the Bracken Broad habitat class for 2007. This does not include bracken present in scattered patches at low frond densities, in woodland or in linear features. The evidence suggests that the estimates for broad habitat bracken needs to be multiplied by at least four to provide estimates of current total bracken-infested land.
- Bracken growth with increasing areas of dense bracken, coupled with some expansion into new areas is predicted as a result of climate change and

rewilding/wildling initiatives. Given the potential impacts on animal and human health it is almost incredulous that there is no obvious plan to treat the bracken problem given the potential problems that bracken can cause.

- We know how to control bracken with and without asulam, but the main issue is that it requires a programme of work that extends over many years and requires constant monitoring and adaptive management (i.e. repeat treatments) to keep bracken at low frond density. However, the tools currently at our disposal are those discussed by Braid (1959), the herbicide glyphosate, and the knowledge that treatments are site specific and may need to be continued for many years to effect good control.
- Bracken control protocols will need to be amended (if possible and realistically) within ELMS agreements and equivalent agri-environment agreements.

Where we are

Given the status of asulam since 2012 with continual annual derogations it should be no real surprise that it has been taken off the market. We have been 'caught with our pants down'. Given the potential considerable disbenefits of high and uncontrolled bracken cover within the landscape we suggest the following actions be taken:

Get better estimates of the full extent of the bracken habitat. This could involve:

- Use of AI with remote sensing, possibly combining spectral imagery with digital elevation models and LIDAR to provide nation-wide estimates.
- Re-doing the Countryside Survey measuring all four categories of bracken in areas or patches and bracken in linear features for a comparison with 1990.
- Perhaps this could be augmented with the use of drones using spectral/LIDAR sensors within each Countryside Survey square to remotely-sense bracken cover accurately in the four different bracken cover classes and linear features. The dream scenario would be to be able to fly drones under tree canopies to ground-truth woodland bracken ground cover, but realistically this will probably have to be done by field survey.

- Produce estimates of the amount of land within Agri-environment schemes that were supposed to be managed with asulam to see what else can be achieved. It is also incumbent upon us to assess how effective agri-environment funding has been at controlling bracken.

Investigate improved methods of using the tools that we do have for bracken control, i.e.:

- Developing improved cutting machinery, especially machines that can tackle slopes.
- Developing improved bruising machinery, this needs to be coupled with good experimentation to test whether or under which conditions they work or not. At present bruising must be viewed at best providing inconsistent results (Milligan *et al*., 2016; Marrs *et al*., 2023). Physiological studies looking at the effects of nicks on emerging bracken fronds (mimicking bruising) suggested that the internal plumbing of the fronds is sufficiently robust to preclude this working effectively (Milligan *et al*., 2016).
- Assess other techniques for follow-up treatment, for example, the use of stock grazing to prevent frond recovery. However, this needs to be undertaken with concurrent studies on animal welfare.
- Developing an alternative herbicide that can be used safely *in lieu* of asulam.
- Developing techniques for applying herbicides to upland terrain. As helicopter spraying of herbicides is no longer permitted, research on herbicide applications by ground sprayers or drones needs to be undertaken.
- If there is no replacement for asulam the main contender will be glyphosate. If this is the case then there will need to be an acceptance that some damage to underlying/adjacent ground flora is an inevitable by-product of bracken control.
- Developing weed-wiping technology that can handle slopes and uneven terrain.
- Continued monitoring for asulam and its derivatives in water bodies. If these chemicals remain present in water bodies after asulam is no longer applied then they have to come from another source. This source needs to be identified.

FINALE

In the absence of leadership on this topic we suggest that the efforts of the Bracken Control Group (Anon, 2024) to encourage debate and development of appropriate new approaches to bracken control in the post-asulam era be supported by government agencies and stakeholders. This will inevitably require additional research funding, which should be informed by close engagement with the Bracken Control Group.

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