A review of Manx Shearwater habitat restoration – learning from 19 years of experience on Copeland Bird Observatory

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Summary

The Copeland Bird Observatory manages Bracken-infested areas (*Pteridium aquilinum*) on Lighthouse Island, aiming to progressively restore and maintain species-rich grassland habitat of benefit to Manx Shearwater, biodiversity, visitors, and bird ringers. Since the start of the restoration programme in 1996, over two hectares of habitat have been brought under management by Bracken and tall herb cutting and biomass removal.

Our review outlines the restoration programme, assesses outcomes on vegetation structure and composition, and identifies the processes driving change. It shows that the management programme has:

- Restored and created a network of areas and wide, short-sward grassy access paths that facilitates bird population monitoring by CBO members and bird observation by visitors and mitigates trampling risk to Manx Shearwater nesting burrows and fledglings.
- Restored coastal, species-rich dry acid grassland from Bracken stands, to improve the condition of Manx Shearwater and Rabbit populations.
- Demonstrated that restoration can be achieved by regular, seasonally distributed cutting and biomass removal carried out annually over a decadal time-scale.
- Established a site-specific ecological basis for adaptive management decision-making.

The cumulative impact of cutting and biomass removal has been a gradual reduction in Bracken cover, surface organic litter depth and the macronutrient content of the plant/soil system and a progressive establishment of species-rich acidic grassland with a root-mat, providing resilience of burrows to trampling and increased foraging capacity for rabbits. Cutting and removal reduces Bracken rhizome macronutrient capacity and sequestration (in particular nitrogen and phosphorus), increases soil organic matter mineralisation and nitrogen leaching from the soil system. Through time these processes render Bracken and tall herbs, in particular Red Campion (*Silene dioica*), less competitive and facilitate natural colonisation by a wide range of stress-tolerant grassland species.

The review develops a site-specific outcome model:

- Early-stage (2-5 years) of reduced Bracken vigour and increased Red Campion (S*ilene dioica*) abundance.
- Mid-stage (3-15 years) of reduced Bracken and Red Campion abundance and increased grass and Ragwort (*Senecio jacobaea*) abundance.
- Late-stage (10-20 years) of short-sward species-rich grassland on well-draining dry to moist acidic soils.

Progress to the grassland late-stage occurs more rapidly in areas with scattered Bracken compared with dense Bracken. Regression, characterised by increased tall herb species and Bracken, is associated with reduced cutting. It occurs more rapidly where restoration is at the early or mid-stages.

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The review also considers the likely outcomes and risks of implementing alternative management options. A key issue considered, is whether to use Asulam to control Bracken as part of the restoration programme.

We conclude that:

- Evidence demonstrating that Asulam treatment would have no negative impact (directly or indirectly) on Manx Shearwater, or that its use would contribute to species-rich coastal grassland restoration, is lacking from the scientific literature.[1]

- Asulam is highly toxic to Bracken plant species from the dock family (*Polygonaceae*) and it is directly and indirectly toxic to a wide range wide range of bryophytes, soil organisms, birds and invertebrates.

- Bracken control by Asulam without removing dead fronds, does not address their sequestered macronutrients.

- Negative outcomes of Asulam spraying on species and habitats on a conservation site with statutory biodiversity protection could result in reputational damage.

Contents

Introduction

Lighthouse Island has statutory conservation protection as part of the Copeland Islands Area of Special Protection Area (SPA) and as an Area of Special Scientific Interest (ASSI). A key protected conservation feature is a breeding population of the priority species Manx Shearwater *Puffinus puffinus* (NIEA 2010, 2004) associated with the priority habitats *Marine Cliff and Slopes* and *Lowland Dry Acid Grassland* (DAERA 2018). These habitats are under threat and in need of conservation action (DAERA 2015).

The Manx Shearwater colony associated with the Copeland Bird Observatory mainly uses existing and abandoned Rabbit burrows to nest in, each pair laying a single egg in the Spring and rearing a pullus which fledges from late August to late October (CBO 2018). Manx Shearwater pulli often congregate in open sward areas at night during August and early September and adults use open areas to take off and land (Ian McKee, *per. obs.*).

The presence and management of short-sward grassland is important to Manx Shearwater colony condition in providing foraging habitat for Rabbits (NIEA 2010, CBO 2018). The dense canopy and deep surface litter of a Bracken stand suppresses grassland species (Marrs and Watt, 2006, Cox et al., 2008) and modifies soil structure (Milligan et al 2018). Manx Shearwater burrows under Bracken with deep litter are therefore more prone to collapse from trampling by ringers and visitors (WTSW, 2015).

Restoring grass-heath vegetation from stands of dense Bracken has been shown to be feasible on a 10-20 year decadal time-scale (Milligan et al 2008). It is known to require a combination of Bracken control and restoration treatments defined to take site-specific ecosystem attributes into consideration (Cox et al 2008). The impact of repeated cutting is to progressively reduce Bracken vigor and facilitate the establishment of grass-heath species tolerant to lower soil macronutrient levels (Milligan et al 2008). The restoration time-scale is limited by the rate at which macronutrients (mainly nitrogen and phosphorus sequestered in surface litter and underground Bracken rhizomes) are released into the soil through mineralisation and lost to the system by leaching (Milligan et al 2008).

General guidelines for ecological restoration (Whisenant, 1999) relevant to CBO include: (1) treat causes rather than symptoms and (2) Emphasize process repair over structural replacement, and (3) design landscapes to encourage positive animal interactions. In the context of restoration on CBO: the symptom was an increase in bracken cover to the detriment of semi-natural grasslands; and the cause was an enrichment of soils leading to progression of succession. This suggests that the bracken should not be treated as a species to eradicate, rather the aim should be to restore the semi-natural grassland. Kettering (2011) shows, from a systematic review and meta-analysis, that attempts to eradicate invasive species often do not yield the desired results, due to re-invasion by the original species or the establishment of a novel invader.

Review by Pakeman et al (2001) proposed that to achieve long-term, cost-efficient, sustainable management of Bracken, the control strategy must: consider the effects on current biodiversity and neighbouring sites; develop management objectives; assess the advantages, disadvantages and likely success of alternative control methods; implement follow up treatments; decide on subsequent vegetation management.

Patterson (2000), in assessing a number of studies, found that “poor” bracken control failed to produce meaningful reductions in either bracken litter or frond cover and there was poor establishment of ground vegetation. The converse was true of for the plant community where “good” control was achieved, with the creation of bare ground free of litter (space was available for colonising species) and the expansion of moss species.

Conservation management to restore grassland from Bracken dominated vegetation is carried out on Lighthouse Island by Copeland Bird Observatory (CBO) volunteers. Action aims to conform to the legal requirements of the SPA and ASSI citation documents, the objectives of which aim to ensure that priority species and habitats are maintained or restored to Favourable Conservation Status (FCS). Management operations also aim to satisfy the conservation and monitoring functions of the CBO.

An adaptive approach to Manx Shearwater habitat conservation management is in place to restore the short-sward grassland habitat of benefit to the long-term sustainability of the colony, and to reduce detrimental impacts of accessing sub-colonies for observational, monitoring and visitors. Within the constraints of available funding and volunteer resources, the main CBO conservation management objectives are to:

- Maintain areas of grassland associated with Manx Shearwater sub-colonies in a favourable condition and restore areas from Bracken to short sward grassland.
- Facilitate access to Manx Shearwater sub-colonies for population monitoring purposes and provide responsible access around the island for visitors so that there is no direct or indirect, cumulative long-term impact on the breeding population.

The main aim of our report is to outline the restoration programme, assess its outcomes and address options for conservation management. The rationale is to contribute to an understanding of how good-practice restoration, based on ecological science (Paterson et al., 2000; Milligan et al., 2018) can maintain effective long-term management of the Manx Shearwater population and ensure that continued access can be managed in a responsible way.

Site description

Lighthouse Island is about 18 hectares or 40 acres in size, and is 40 metres high at its maximum (CBO annual report, 2010). The bedrock is strongly folded and faulted greywacke. The soils are largely free-draining, shallow (*ca.* 30 cm, ranging from 1-56 cm), acidic (pH 4.5), highly organic and sandy (Rhodes 2017). Our field survey found a small area of basal boulder clay in an excavated soil pit, suggesting a patchy distribution across parts of the island. The topography is gently sloping, with water-receiving slopes, periodically flushed gullies and occasional wet hollows with impeded drainage.

Fig 1. Satellite image (c.2010) of Lighthouse Island.

Until the end of the 19th Century the island was occupied and farmed by two permanent lighthouse keepers and their families (CBO 2018). It was large enough to support goats, sheep, pigs and a donkey. There are also two areas which show evidence of cultivation using lazy beds' (rig and furrow system). At this time grassland would also have been extensive. Rabbits, which are currently the only large herbivores on the island, are said to have been introduced by "the lighthouse keeper".

Land use records refer mainly to activity based around the Cottage lighthouse which was built on the island in 1715 and which became derelict after 1884. There are verbal reports of one person "still living" on the island in the early 20th Century but after this time it became uninhabited and Bracken would have begun to extend into grassland, due largely to the absence of domesticated grazing stock and possibly the positive management of vegetation to sustain them (abandonment). Bracken is also said to have increased following the introduction of the Rabbit disease myxomatosis, probably around the mid-1950s. Rabbits are currently the only large herbivores on the island, reportedly surviving outbreaks of myxomatosis, in particular a serious event in 2010.

The Copeland Bird Observatory (CBO) facility was established in 1954, running and operating on a part-time basis (CBO 2010). Volunteer local amateur ornithologist wardens carry out bird conservation management and monitoring activities of the island on behalf of the National Trust owners.

Bracken cutting and the restoration programme

There are few records of early habitat management by CBO but it is known that some Bracken cutting was carried out before the 1970s. A grassland area and path habitat restoration programme was carried out from 1996 to 2015, gradually incorporating the existing network of paths by 2010. Restoration treatment trials were carried out at different times and locations as operational constraints allowed. The broad objectives developed were to restore short sward grassland from dense Bracken to provide grass foraging areas for Rabbits, and to provide responsible access paths for CBO monitoring and visitors.

By 2012 a structured mowing programme covered an estimated 2.0 ha of habitat (about 10% of the land area above mean high tide). The estimate was based on 2010 field mapping of two-thirds of the mowed paths and area dimensions (m), with the other one-third estimated from aerial photographs. From 2005 to 2015, mowing frequency was between 1 and 5 times a year, with seasonal distribution between late April and October (Appendix V). Mowing frequency was greater on more recently adopted areas of dense Bracken.

There were three phases to the restoration programme:

1. Bracken cutting with cut biomass removed. During the 1970s and early 1980s occasional hand scything, with cuttings usually raked and removed, was carried out. CBO members report that this "did not take very long". At this time a mid-1980s charter flight aerial photograph showed that Bracken cover was much less than it is currently (Appendix 1).

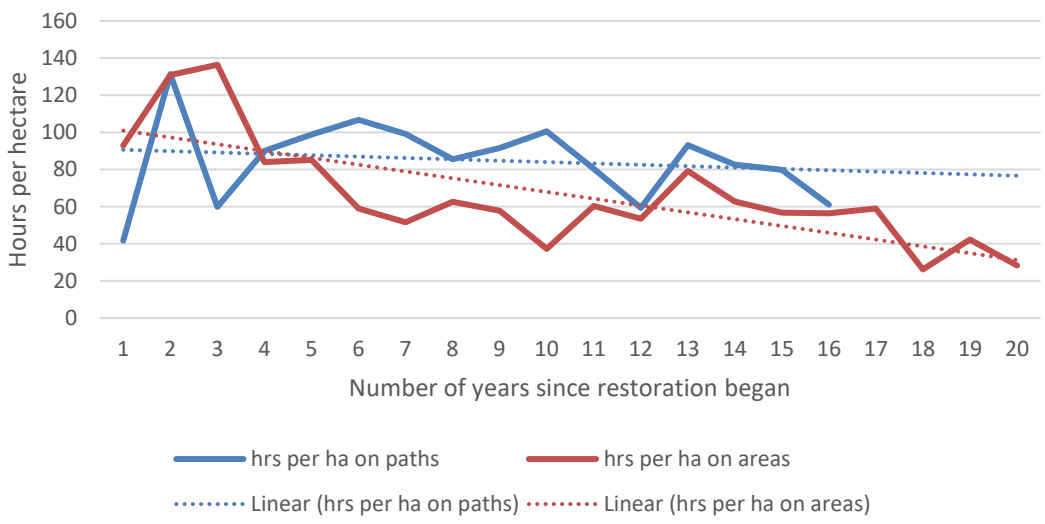
2. Bracken cutting with cut biomass left in place. From about 1986 to 2005 mechanised sickle mowers were used to cut a greater area of dense Bracken and to clear more paths than previously possible. Cuttings were usually discarded beside the machine within the treated areas/paths. Between 2000 and 2009, the sickle mower and a powered strimmer were decreasingly used to clear paths on an infrequent basis, usually only on paths that had not yet been adopted into the mowing programme. Observations over the long term concluded that this method was counter-productive, because bracken and red campion vigour and spread increased.

3. Bracken cutting and biomass removal. Following trials on a small area in the North Garden (0.1 ha) in 1996, this method was introduced gradually as the restoration standard. From 1996 to 2018 cutting was carried out with commercial-grade lawnmowers to cope with the challenging terrain and vegetation. The cut biomass was removed and piled. The frequency of mowing on each area or path decreased from 2016 to 2018 inclusive, with all receiving the first cut in mid-summer, and some areas being abandoned. Mowing Bracken was relatively easy when using these more powerful mower machines, and by carrying out the first seasonal treatment in mid to late May before bracken fronds had reached a mature height and density.

Much mowing was needed during the first 2-5 years of restoration (Fig. 2) due to prolific growth of Red Campion, Yorkshire fog *Holcus lanatus* and Blue-bell *Endymion non-scripta*. Delays in mowing events in season led to difficult mowing which took longer, so a regular optimal frequency was adopted. A consistent effort from volunteers was required to progress the restoration process, especially in the first few years of restoration when the vegetation response was vigorous.

The main access paths were adopted in 1999 and 2000 and additional areas on Manx Shearwater sub-colonies were included in 2006. By 2012 all access routes cut previously by sickle mower (including Manx Shearwater sub-colonies) had been included in the restoration programme. A 'CBO mowing manual' was prepared to document best practice to encourage efficiency (McKee, 2016).

Fig. 2 Number of hours per hectare to mow a sub set of paths and areas since restoration began



Main points

- Observations over the long term concluded that the method leaving cuttings in situ was counter-productive, because bracken and red campion vigour and spread increased.
- The feasible manageable area of cutting is limited by operational constraints on volunteer numbers and resources. Consideration of potential damage to Manx Shearwater burrow integrity constrains any introduction of large agricultural management machinery.
- Mechanical cutting by rugged commercial self-propelled mowers, with a weight of less than 30kg per axle, with adaptive working mitigations, has proven feasible without causing burrow collapse.

Changes in the extent of Bracken cover

Available earth images, aerial photographs (chartered flights in the 1980s) and ground photographs (late 1970s) were used to assess broad habitat distribution between the 1980s and 2016. Changes in Bracken cover could be identified despite differences in the time of year the images and photographs were captured (see appendix II).

From the 1980s, the extent of Bracken had increased over time so that by the early 2003, areas of former grassland habitat and areas of grassland with scattered Bracken had developed a dense Bracken cover. By the 2010s, most of the open habitat and paths on the Island were being maintained by regular mowing. The main impact of restoration was evident on the 2012 earth image, with the area of Bracken cutting and biomass removal estimated at more than two hectares.

Early-stage impact of restoration

Field notes and ground photographs taken during the restoration programme 1996-2018 were used to provide a qualitative record of the initial impact of cutting on vegetation structure and species composition as cutting progressed. This section summarises key observations.

In the early stages of Bracken cutting (3 to 4+ years) there was noticeable reduction in Bracken cover. During this this time there were marked increases in the abundance of a range of tall-herb species (in particular Red Campion) and Yorkshire fog became abundant. Regular treatment (cutting and biomass removed) between two and five times a year reduced vegetation height to 10-20 cm.

Delay in cutting until July during the early years led to a rapid increase in tall herb species, in particular Red Campion and on some sites Stinging-nettle *Urtica dioica*. Late cutting (beyond mid-May) also facilitated Blue-bell which then constrained species palatable to Rabbits at a time when forage was at a premium. If cutting was missed extra work was subsequently needed to cut and remove recovering vegetation. It was also important to maintain the area cut in previous years and not allow Bracken to invade at boundary edges. On paths, cut Blue-bell biomass created slippery walking conditions.

On areas and paths close to the shore, early seasonal cutting (before June) was needed to to prevent tall vegetation developing, thereby discouraging gulls from micro-siting nests on paths that would be well used later in the nesting season. Otherwise, this would present an attractive habitat for gull and tern nestlings to hide in, increasing the risk of loss to trampling or subsequent mowing. Early cutting across the Manx Shearwater sub colonies also reduced the risk of ringers trampling chicks and adult Manx Shearwaters at night, as shadows produced by torches were shorter behind low lying red campion.

With regular cutting of Bracken and Red Campion (Appendix III), biomass production was progressively reduced to the extent that grasses were able to increase or establish after about 3-10 years and the number of hours spent cutting could be reduced (Fig. 2). The speed of red campion suppression coupled with the establishment of grasses appeared to be related to the mowing effort, and more importantly, the amount of bracken litter present. Grass cover was more apparent where Bracken was less dense and where grass was already present in the understorey. In these locations, Rabbit foraging contributed to a reduced need for cutting.

Main points

- Cutting and biomass removal to reduce Bracken and Red Campion abundance needed to be high in the early stages of restoration to control regrowth and maximise biomass cropping. An early growing-season cut, a mid-season cut and a late-cut each year restricted vegetation height to 10-20cm and led to grass establishment after about 3-10 years.
- The total mowing input needed to maintain areas and paths under restoration and also to begin additional restoration, declined with time, varying from 160 - 217 hours in the years from 2009 through to 2014, to under 130 hours in 2015.

Impact of cutting on Manx Shearwater nest sites

Field observation showed that trampling during Bracken cutting and access to observation sites by bird-ringers and visitors could collapse nest burrows. Collapse was less likely in short-sward grass habitat and more likely under a dense Bracken canopy (*pers. obs.* Ian McKee). Indeed, a necessary mitigation on Skomer, Wales is that access to Bracken dominated areas for ringing purposes must be restricted to crawling on hands and knees. Damage occurs when visitors do not follow this mitigation (WTSW, 2015).

Shallow pits dug in tall Bracken habitat, showed frond litter (c. 5cm deep) over an organic sandy soil with few roots and a crumbly texture (Fig. 3). Below this were Bracken rhizomes. Soil structure under a nearby short-sward grassland had an organic surface horizon (1-2 cm) with a dense, firm-textured, fibrous root mass, below which grass sward roots were frequent at up to 15 cm depth.

Out of four Manx Shearwater observation burrows located in 2015 close to the vegetation quadrats on South Promontory, two had collapsed, so the burrows were no longer used. As a result, the numbered flagstone markers were moved to new burrows by 2018. These were on ground that did not have a grassy cover, and led to flagstones collapsing a burrow.

Red Campion dominated soils were more prone to burrow collapse due to the high shoot/root ratio and forager root structure, compared to the dense root-mat of grassy swards, which develop as soil macronutrient levels decline. Asulam spraying of Bracken (in isolation without mowing) is highly likely to result in encouraging access across areas vulnerable to burrow collapse, which without access prevention and management, would result in a cumulative negative impact on the Manx Shearwater colony.

Main point

- Differences in root biomass distribution probably contribute to a greater resilience of Manx Shearwater burrows to trampling damage and disturbance in short grass sward, compared with dense Bracken stands and/or a Red campion dominated field layer.

Fig 3. Surface soil structure under:

a) Dense bracken

b) Short grass sward

Community structure of the grassland restoration target

There is a comprehensive inventory of plant species recorded on the Island (CEDaR 2018), but little information on variation in plant community structure. The aim of this section is to: describe the grassland species composition and structure of the grassland habitat; compare the community with other types of lowland grassland in Ireland; and assess whether it is an appropriate ecological target for the restoration programme.

Ecological data on Manx Shearwater burrow density, population numbers and colony dynamics on the Island is not yet available, e.g. the types of habitat favoured by Manx Shearwater for nesting and rearing fledglings. Factors affecting burrow density, population numbers, and colony dynamics would need to be assessed from meta-analysis of North Atlantic habitat nest sites.

Field survey was carried out in early September 2018 to record the percentage cover of each species in nine square sample quadrats (2m by 2m). Quadrats were located in typically representative well-draining grassland habitat. Two had no history of Bracken invasion (q10, q14); in one, cutting had ceased recently (q28); in four (q1, q11, q27, q31), cutting had been reduced recently; one (q26) was still in the restoration programme; and one (not part of the programme) was near-natural cliff-top

grassland without Bracken. Quadrats 10, 14, 28, 1, 11, 27 had no Bracken and in quadrats 31 and 26 there were occasional invasive Bracken fronds.

Table 1. Species composition of well-draining dry to moist representative grassland quadrats.

Species	Mean % frequency	Mean % cover
Agrostis capillaris	100	72
Senecio jacobaea	89	6
Sagina procumbens	78	2
Silene dioica	78	3
Kindbergia praelongum	67	7
Campothecium introflexus	56	10
Cladonia floekiana	56	2
Ranunculus repens	56	2
Bryum pallens	44	4
Holcus lanatus	44	2
Hydrocotyle vulgaris	44	1
Scapania irrigua	44	11
Conocephalum conicum	33	1
Galium saxatile	33	1
Nardia geoscyphus	33	3
Prunella vulgaris	33	1
Rumex acetosella	33	3
Mean number of species q^{-1}	*14*	
Other species: *Bracythecium sp., Bryum capillare, Calliegonelia cuspdatum, Cardamine pratensis, Cerastium fontanum, Chiloscyphus polyanthus, Cirsium arvense, Ditrichum heteromallum, Hypnum cupressiforme, Leiocolea turbinata, Lophocolea bidentata, Lotus corniculatus, Mnium hornum, Myosotus arvensis, Peltigera membranacea, Plagiomnium cuspidatum, Poa pratensis, Poa trivialis, Polytrichum aloides, Pteridium aquilnum, Ranunculus flammula, Sedum anglicum, Silene uniflora, Spergularia rupicola, Trifolium repens, Tripleurospermum maritima, Urtica dioica, Viola riviniana.*		

Calcifuge species indicative of acidic soils are frequent (Table 1), for example, Common bent-grass *Agrostis capillaris* is abundant, and *Cladonia floekiana*, *Campothecium introflexus*, *Scapania irrigua* and *Rumex acetosella* are frequent. Other species with a quite different ecology also occur, for example ruderals of disturbed habitats such as Ragwort *Senecio jacobaea* and Pearlwort *Sagina procumbens*. The nitrophile Red Campion *Silene dioica*, with its fine, forager-type root system (Fitter 1999) is frequent, bryophytes are frequent and there are also species indicative of moist to temporarily flushed (but otherwise well-draining) soils, eg., *Hydrocotyle vulgaris* and *Ranunculus repens*.

The quadrats show some affinity with the NI priority habitat, Lowland dry acid grassland (DAERA 2018) a type of NI species-rich, lowland, coastal, dry to moist well-draining semi-natural acid grassland which occupies a small percentage area of Northern Ireland. They are also loosely related to *U1 Festuca ovina-Agrostis capillaris-Rumex acetosella* grassland (Rodwell 1992), a British community with a dominant cover of Common bent-grass, an extensive bryophyte cover, and coarse weedy species present, in particular ragwort which is largely restricted to summer-parched, base-poor soils of southern Britain, characteristically grazed by Rabbits.

Main points

- Typical Island grassland in the restoration programme is dominated by Common bent-grass and has a species composition similar to species-rich, dry-to moist acid grassland priority habitat.
- The dry to moist, well-draining grassland provides an indicative, site-specific ecological template for the restoration programme to target.

Fig. 4. a) Semi-natural dry grassland mosaic with scattered Bracken, b) Semi-natural moist grassland.

a)

b)

Long-term impact of Bracken cutting and restoration

This section summarises the impact of Bracken cutting dating from 1986 and the main restoration programme from 1996 to 2018. Quadrat sampling was carried out in September 2015, prior to the final mowing treatment of that season. Twenty-six square quadrats (2m by 2m) were located in typically representative vegetation on organic, sandy soils of the Bracken restoration programme. Two dense, uncut Bracken quadrats were also sampled for reference. In each quadrat, records were made for each species of higher plant cover, total pleurocarp cover; total acrocarp cover, Great- scented liverwort *Conocephalum conicum cover* and lichen cover. Vegetation height, environment variables and management cutting history were recorded (Table 2b) and ground photographic records were made of each quadrat and its location (Appendix IV).

Resurvey of the 2015 quadrats, was carried out in 2018 using the same procedures, except that each bryophyte and lichen species was recorded separately. For comparative analytical purposes, bryophyte species were aggregated to give total pleurocarp and total acrocarp cover. Quadrat relocation was guided by 2015 photographs and measures from known fixed points. A numerical classification of the 2018 quadrats (Hill and Šmilauer, 2005) gave four main groups (Table 2a,2b).

Group 1. Dry, well-draining grassland. This represents short, species-rich, Rabbit-grazed vegetation dominated by Common bent-grass *Agrostis capillaris*. The group is characterised by Earth star-moss *Campothecium introflexus* and other species indicative of low nutrient status, acidic soils, *eg.*, Cup-lichen *Cladonia* floerkiana, Sheep's sorrel *Rumex acetosella*, Red Campion *Silene dioica*, Pearlwort *Sagina procumbens* and Ragwort *Senecio jacobaea*. Species of disturbed habitats are also frequent and there are occasional scattered Bracken fronds. The cutting input (total seasonal cuts) is relatively low.

Group 2. Moist, well-draining grassland. This represents short, species-rich, Rabbit-grazed vegetation with mainly Common bent-grass *Agrostis capillaris*, Rough-stalked meadow-grass *Poa trivialis* and Ragwort Senecio jacobaea. The wetland species Marsh pennywort *Hydrocotyle vulgaris* and Creeping buttercup *Ranunculus repens* are abundant and the Great-scented liverwort *Conocephalum conicum* and Heath earwort *Scapania irrigua* occur in seasonally flushed areas. Bracken cover is low and cutting input is relatively low after 5 to 10 years.

Group 3. Tall herb vegetation. Ragwort *Senecio jacobaea*, the nitriphile Red Campion, *Silene dioica,* Rough-stalked meadow-grass *Poa trivialis* and patchy Maritime campion *Silene maritima* are the main species. A high cutting input maintains a relatively short vegetation. Ground surface slope is greater than in the grassland groups, and Rabbit digging is frequent.

Group 4. Bracken dominated tall vegetation. The ground cover is mainly regrowth Bracken *Pteridium aquilinum,* which can have an understorey of Red Campion *Silene dioica* and Ragwort *Senecio jacobaea*. Other frequent species occurring with low cover values are Feather-moss *Kindbergia praelongum*, Rough-stalked meadow grass *Poa trivialis* and Yorkshire fog *Holcus lanatus*. There is much bare soil and organic litter, and Rabbit digging is frequent. A high cutting input is related to the relatively recent adoption of some areas into the restoration programme.

Table 2a. Mean group percentage frequency (F) and cover (C).

Species	Group 1		Group 2		Group 3		Group 4	
	F	C	F	C	F	C	F	C
Agrostis capillaris	**100**	*63.0*	**75**	*49.1*	**44**	*2.6*	**29**	*0.4*
Campothecium introflexus	**100**	*18.1*	**-**	*-*	**-**	*-*	**14**	*<0.1*
Cladonia floerkiana	**75**	*3.8*	**25**	*0.3*	**-**	*-*	**14**	*<0.1*
Conocephalum conicum	**-**	*-*	**75**	*1.7*	**11**	*0.3*	**-**	*-*
Kindbergia praelongum	**75**	*13.5*	**63**	*1.5*	**44**	*1.3*	**57**	*1.4*
Holcus lanatus	**50**	*1.3*	**63**	*1.8*	**67**	*1.7*	**57**	*0.9*
Hydrocotyle vulgaris	**25**	*0.3*	**63**	*10.4*	**-**	*-*	**-**	*-*
Nardia geoscyphus	**50**	*6.3*	**13**	*0.1*	**-**	*-*	**-**	*-*
Poa trivialis	**25**	*0.6*	**38**	*15.8*	**100**	*4.2*	**57**	*1.4*
Pteridium aquilinum	**50**	*4.8*	**13**	*2.3*	**67**	*3.9*	**100**	*68.9*
Ranunculus repens	**25**	*0.3*	**100**	*8.9*	**56**	*2.4*	**-**	*-*
Rumex acetosella	**50**	*6.3*	**-**	*-*	**22**	*0.1*	**-**	*-*
Sagina procumbens	**75**	*1.5*	**88**	*6.1*	**67**	*2.4*	**14**	*0.4*
Scapania irrigua	**25**	*7.4*	**50**	*9.9*	**-**	*-*	**-**	*-*
Senecio jacobaea	**75**	*5.8*	**100**	*10.6*	**100**	*20.1*	**57**	*5.6*
Silene uniflora	**-**	*-*	**-**	*-*	**56**	*12.4*	**14**	*0.4*
Silene dioica	**75**	*3.0*	**50**	*4.5*	**89**	*15.7*	**100**	*48.8*
Tripleurospermum maritima	**-**	*-*	**50**	*6.6*	**22**	*0.6*	29	*0.5*
Number of quadrats	*4*		*8*		*9*		*7*	
Number of species.	*29*		*46*		*27*		*16*	
Mean number of species	*16*		*16*		*10*		*12*	
Other species recorded: *Bracythecium sp., Bryum capillare, Calliergonelia cuspidatum, Cardamine pratensis, Cerastium fontanum, Chiloscyphus polyanthus, Cirsium arvense, Ditrichum heteromallum, Hypnum cupressiforme, Leiocolea turbinata, Lophocolea bicuspitata, Lotus corniculatus, Mnium hornum, Myosotus arvensis, Peltigera membranacea, Plagiomnium cuspidatum, Poa pratensis, Polytrichum aloides, Ranunculus flammula, Sedum anglicum, Trifolium repens, Urtica dioica, Viola riviniana.*								

Table 2b. Environment and management mean attributes in vegetation groups.

Environment	Group 1	Group 2	Group 3	Group 4
Slope (degrees)	2.0	2.4	3.7	2.4
Bare soil cover (%)	1.9	0.3	4.3	8.1
Water receiving topography (%)	25	75	0	0
Rabbit digging present (%)	0	0	44	14
Rabbit droppings present (%)	75	63	89	71
Water receiving topography (%)	25	75	0	0
Unmanaged (%)	25	13	0	29
Number of years cut	12	16.7	11.7	9.2
Number of seasonal cuts	25.5	54.4	46.6	35.8
Vegetation height (cm)	0.4	2.4	6.7	6.0
Maximum veg height (cm)	12.1	14.3	20.3	29
Quadrat number	4	8	9	7

Main points

- The Bracken and tall herb vegetation groups represent early-stage and mid-stage restoration from dense Bracken stands.

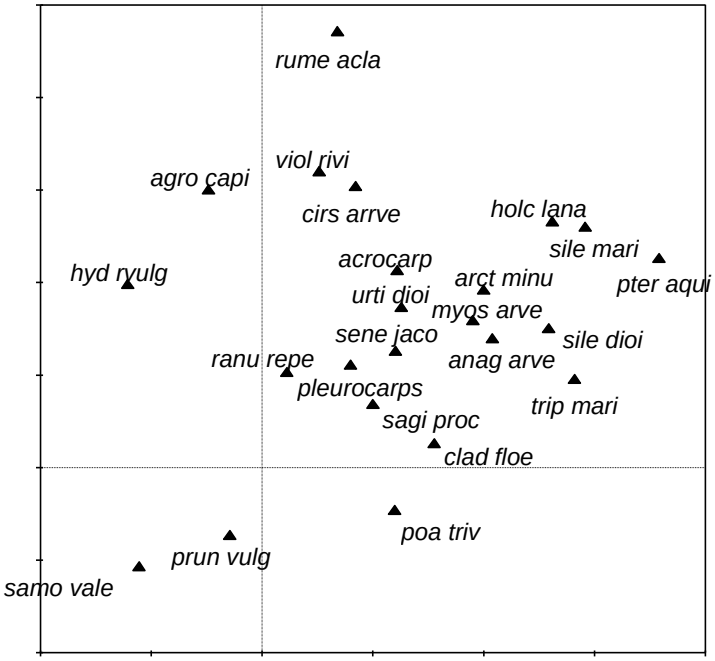
- The short-sward grassland groups represent later-stages of restoration from dense and less dense Bracken stands on well-draining, dry acidic soils and well-draining, moist, acidic soils.

Impact of the restoration programme to 2015

This section describes the underlying influence of environment and management on the 2015 dataset. Assessment was with an ordination technique (Detrended Correspondance Analysis), (ter Braak and Smilauer 1998) with results displayed as ordination diagrams (Figs. 1a-c)

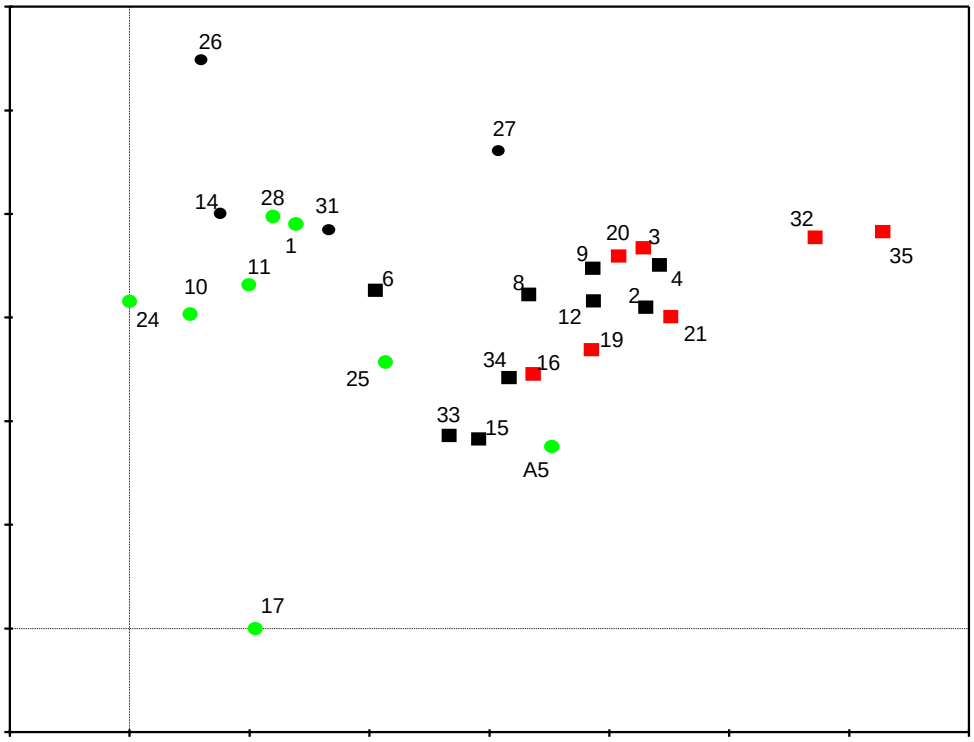
Fig. 5a, b, c. DCA ordination diagrams. Each axis represents the location of species and quadrats along underlying environmental gradients influencing the vegetation.

Fig 5a. Species diagram: The most abundant species in the 2015 quadrats are shown. Species in a similar part of the diagram have a similar ecology. Well separated species have contrasting ecological tolerances and preferences. Plant names: genus/species = 8 letter binomial code



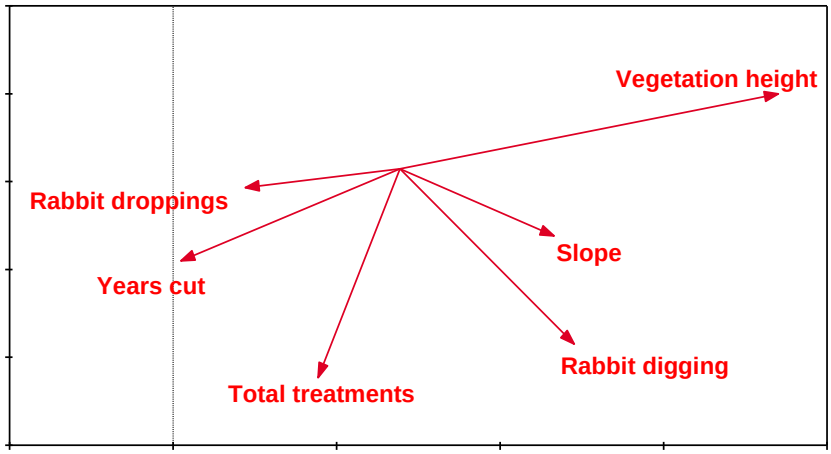
Tall herbs and Bracken (*pter aqui*) indicative of ungrazed habitats and nutrient-rich soils occur on the right of the ordination (Fig 1a), with species indicative of grassland habitats eg., Common bent-grass (a*gro capi*) and Creeping buttercup (*ranu repe*) occurring on the left. Variation in species composition along the axis (right to left) suggests an increasing impact of cutting/grazing.

Fig 5b. Quadrat diagram (2015). Quadrat number and Community group (Group 1 - black circles; Group 2 - green circles; Group 3 - black squares; Group 4 - red squares). Reference quadrats are: dense Bracken, q32, q35; grassland, q10, q14.



Dry and moist, well-draining grassy quadrats (community groups 1 and 2) are towards the left of the ordination, with tall herb add bracken quadrats (groups 3 and 4) towards the right (Fig 5b). Two dense Bracken reference quadrats with no history of cutting treatment (q32, q35) are on the far right. Two semi-natural grassland quadrats without a history of cutting treatment (q10, q14) are to the left. The spatial separation of quadrat groups right to left suggests an increasing impact of cutting/grazing.

Fig 5c. Environment/management diagram (2015): The arrow-vector length and direction of an environment/management attribute, represents the strength of positive correlation with species and quadrat on diagrams (Figs a and b).



The underlying influence of cutting and rabbit grazing is indicated by the direction of vectors representing the number of years with cutting the total number of cuts carried out and the frequency of Rabbit

droppings, all of which increase from top right to bottom left (Fig 5c). Vegetation height increases toward the top right, a direct result of the cutting process.

The ordination models the key impact of the restoration programme of modifying species composition, from early-stage community group 4 with abundant Bracken (Table 1) to mid-stage community group 3 with tall herb /ruderal vegetation, and then to later-stage community groups 1-2. The impact on key species, is to decrease Bracken and Red Campion cover and increase Common bent-grass cover (Figs. 5a-c).

Main points

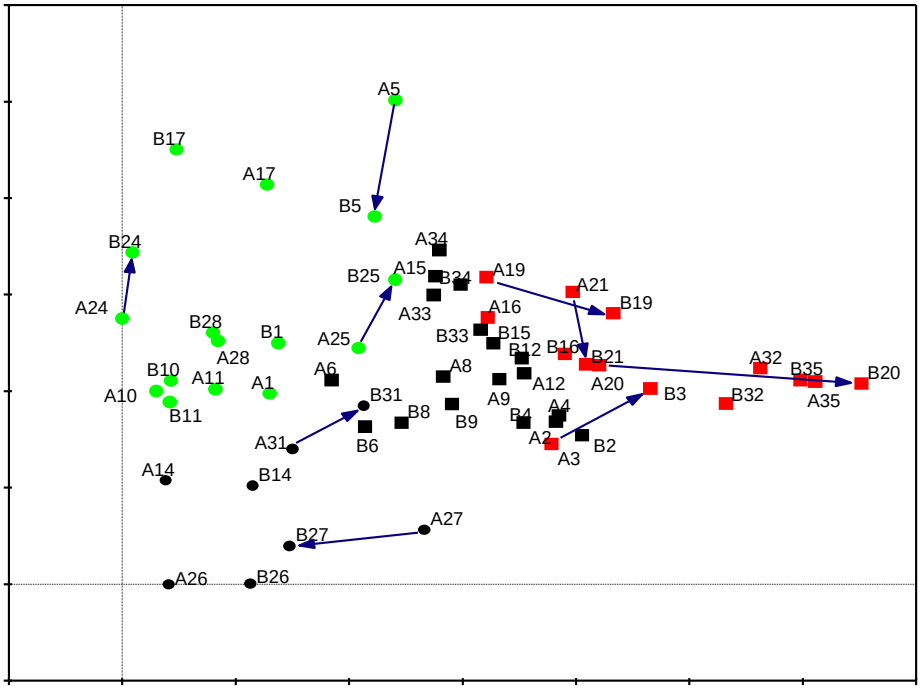
- The restoration programme to 2015 reduces the abundance and vigour of the key early-stage species, Bracken and Red Campion and it increases the abundance of the late-stage restoration species Common bent-grass.
- Restoration drives species composition towards late-stage species-rich acid grassland development.
- Decrease in the abundance of soil nitrogen indicator species as restoration proceeds, points to a reduced soil macronutrient nutrient status with time.
- Increase in abundance of late-stage restoration species may indicate a reduced plant available Phosphorus status.

Impact of cutting 2016-2018

This section models vegetation change between 2016 and 2018, a period when cutting input was reduced in frequency or had ceased in some areas and paths. Paired quadrats from 2015 (at the end of the growing season) and 2018 were ordinated to assess change in species composition with time (Figs. 6a-c).

On the diagram, the length and direction of the arrows connecting paired quadrats (Fig 6a) represent the magnitude of species composition change (6b) in relation to underlying environment/management gradients (6c). The ordination axes represent the same underlying environmental gradients as in the section on long-term impact above, but the vertical axis is reversed.

Fig. 6a. Paired quadrats diagram (A = 2015; B = 2018). Dense Bracken reference quadrats are: q32, 35; Grassland reference quadrats are: q10, q14. Community group 1 - black circles; Group 2 - black squares; Group 3 – green circles; Group 4 - red squares. For clarity, only shifts in quadrats with reduced management are vectored. Vector length represents the magnitude of species composition difference between survey times 2015 and 2018.

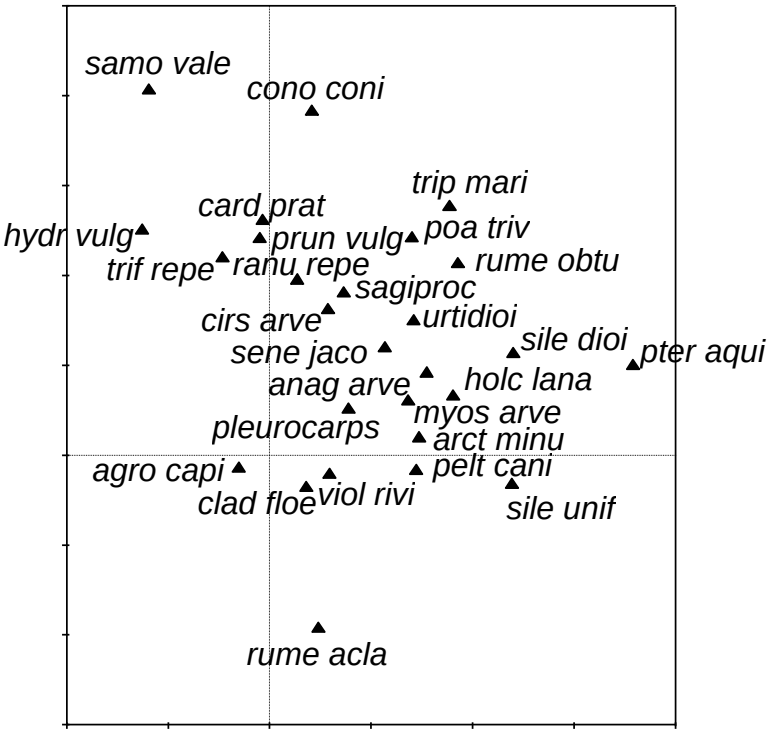


Spatial shifts of the reference quadrat 10 (Rabbit-grazed with abundant Common bent-grass) and reference quadrats q32, q35 (dense Bracken), were small (indicating few composition differences). In reference quadrat q14 (Rabbit-grazed with abundant Common bent-grass) the shift was larger, moving toward a composition with increased Red Campion abundance, indicative of habitat regression.

Shifts in quadrats where cutting had been reduced were usually greater than in quadrats where regular cutting had been maintained. Quadrats 3, 19, 20, 21 (in the Bracken community group 4), where there had been no cutting between 2015 and 2018, the direction of shift was towards the right, associated with increased Bracken and tall herb abundance. Shifts in quadrats 5, 24, 25, 27, 31 (in community groups 1 and 2) where cutting input had been reduced, were associated with an increase in the abundance of species such as Ragwort, Creeping buttercup, Rough meadow-grass and Marsh pennywort. In these quadrats shift represent a vegetation regression process. Shift was greatest towards in quadrats from community group 4 where restoration had been in operation for the least time and where the total number of treatments was smallest (Fig. 6c).

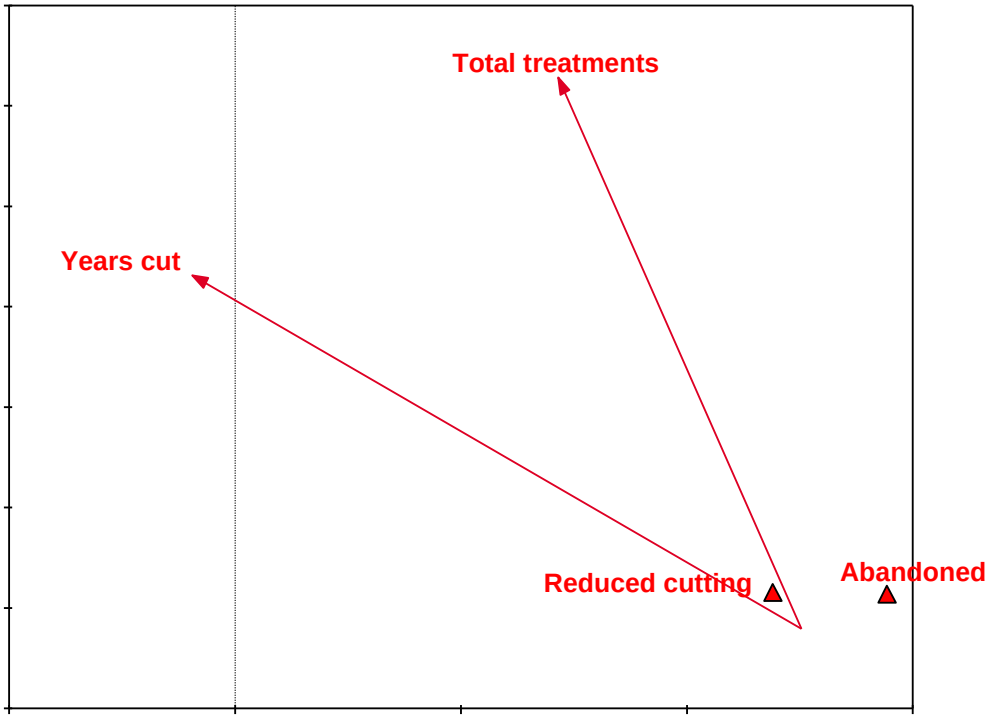
Shifts in quadrats where the cutting regime had not changed were small, except for: q16 in which Bracken cover had increased; q17 in which pennywort cover had increased; q26 in which cup-lichen and pleurocarp cover had increased, and in q33 in which Red Campion cover had increased

Fig. 6b. Species diagram: The most abundant species in the baseline and resurvey quadrats 2015- 2018 are shown.



Species to the right of the species diagram (Fig 6b) are mainly competitive tall herbs with terminal bud-growth and are susceptible to cutting. They characterise quadrats from community groups 3-4 on nutrient-rich soils showing the largest regression shift. Species to the left have their growing points close to the soil surface and are more tolerant of cutting. The groups in which they occur have a relatively low soil nutrient content, an attribute which limits the rate of regression in response to reduced restoration effort.

Fig. 6c. Management attribute diagram: The length of vector arrows represents the magnitude of change between 2015-2018.



Quadrats from community groups 3-4 showing the greatest regression shifts were those with reduced cutting or abandonment (Fig 6c). Quadrats sowing the least regression shift were those in groups with a long history cutting and which have a relatively low soil nutrient content, attributes which constrain the rate of regression in response to reduced restoration effort.

Main points

- Regression, characterised as tall herb species and Bracken grow-back, occurred when cutting was reduced in the grassland, tall herb and Bracken community group quadrats.
- Regression was greatest where the restoration programme had been in operation for the least time and where cutting input had been highest.
- Future habitat surveillance based on records of key plant species (Bracken, Red Campion, Common bent-grass), and the distribution of Manx Shearwater nest sites and Rabbits could be used to inform adaptive management decision-making.

Overview of restoration progress

The CBO programme of management treatments developed has delivered outcomes in line with the conservation objectives and conforms to the principles of the legal requirements of ASSI citation documents. It has:

- Reduced Bracken frond and tall herb leaf cover and density on about 10% of the island.
- Created a network of wide, grassy access paths for bird population monitoring by CBO members and for bird observation by visitors.
- Improved the condition of grassland species diversity and structure, and soil structural integrity associated with Manx Shearwater nesting areas.
- Restored and maintained grass foraging areas for Rabbits.

After a long period of Bracken control and restoration management (1996-2015), volunteer time and material costs (mainly fuel for cutting machinery) have become smaller, largely on those areas of grassland where the soil nutrient status has been lowered, driven by biomass removal, organic matter mineralisation and soil leaching.

The species composition of this grassland, which is in the late-stage of restoration, is approaching that of near-natural grassland associated with sea cliff tops on the Island, a priority habitat corresponding to the NI priority habitats *Marine Cliff and Slopes* and *Lowland Dry Acid Grassland*. This habitat is a favoured foraging habitat of Rabbits, thought to be important for providing additional burrows for nesting Manx Shearwater.

Since Bracken-cutting for restoration purposes has been carried out regularly since 1996, the time scale for restoring late-stage species-rich acid grassland from dense Bracken seems to be about 20 years. This compares favourably with the 20-year period for restoring grass heath from dense Bracken on peat soils of the Derbyshire Peak District (Milligan et al 2018). However, the CBO Lighthouse Island method had a greater frequency of biomass cropping than the Derbyshire study and greater biomass regrowth. Our study suggests that this is related to the greater soil macronutrient status of the Lighthouse Island soil system and that if cutting and biomass removal is not carried out, regression will occur, and restoration outcome gains to late-stage grassland in good ecological condition will be lost.

Providing safe pathway access to the observatory facilities from boat landing jetties has allowed ringers and visitors to observe Manx Shearwater and other birds across most of the island. It has reduced the risk of trampling damage to nest burrows and fledglings by providing constant and clearly defined routes for walking. The need for visitors to search Bracken and tall herb vegetation, with risk of trampling burrows or nesting birds at night is reduced. The regular programme of cutting and biomass removal, has avoided the need to limit access to Manx Shearwater sub-colonies, as is the case on Skomer and Skokholm islands (Management plan and annual report for 2015), Wales, where Shearwater nest sites suffer from trampling damage if controls are not followed by visitors. Path and Manx Shearwater area access has also increased the efficiency of the monitoring function of CBO.

Constraints on volunteer restoration management 2015-2018, reduced the frequency and extent of Bracken cutting and removal. We have shown that this led to increased Bracken and tall herb abundance and that increase was greatest in areas where restoration had been adopted more recently. It highlights the conservation importance of:

- Continuing with the restoration programme.
- Maintaining an adaptive approach to management.
- Voluntary groups and individuals continuing to maintain and restore ASSI conservation features.
- Monitoring the impact of restoration management.

Conservation management options

Five conservation options are considered in this section:

1. Discontinue habitat and path restoration and management (abandonment).
2. Continue same level of management input as 2015 and before (restoration approach).
3. Reduced management input (restoration approach).
4. Manage Bracken by cutting and fronds left in situ (Control approach).
5. Manage Bracken by herbicide (Asulam) treatment (Control approach).

Details of each option are presented in Appendix I, and a textual presentation of each of the management options is given below. The most likely outcomes and mitigations to reduce the risk of negative impact on the designated features are considered along with related issues of uncertainty, resources, and Observatory operation.

Option 1. Cease habitat and path restoration and management

Without active management, rapid regression to stable-state, dense Bracken habitat would develop on previously managed paths and restored areas. There would be a risk of Bracken invasion into open semi-natural coastal habitat, resulting in decreased species diversity.

Reduction in Manx Shearwater may be experienced over the long term. The rabbit population would enter a decline proportionate to the loss and fragmentation of the foraging habitat areas. They may experience sudden and catastrophic population crashes after disease events, with limited speed and scale of recovery due to the reduced area of foraging available. Progressive expansion of existing areas of scrub/woodland through ecological succession would be possible without rabbits to prevent sapling development.

Regression would be slower on areas in the later stages of restoration to grassland, where soil macronutrient status has been significantly lowered. It would be slowest on short-sward, nutrient-poor, acid grassland without bracken and tall herbs in the sward, and probably on a timescale of 10-20 years.

This would have short to long term implications for the running of the observatory. Clear paths would not be provided for visitors, leading to increased disturbance of nesting birds during the Spring/ Summer. Shearwater burrows would be more prone to collapse if visitor access was allowed over sub-colonies. It would become irresponsible to access large portions of the island during the nesting season, and all year round for Shearwater sub colonies.

Mitigations required Access by walking to any areas with burrows (all Manx Shearwater sub colonies) would need to be prevented, so that immediate and cumulative negative impacts on the integrity of active and unused Manx Shearwater burrows is kept to a minimum. Access to these areas would have to be by crawling on hands and knees, as in Skomer and Skokholm best practice. Large parts of the island would be out of bounds all the year round (since burrow collapse is more prone in the winter when soils are wetter), but some paths could be used, such as the Well path, South path, Cliff path, access to the Gardens, and the Radar.

Poles could be used to mark the areas of bracken than could be walked through, such as those paths mentioned above, and any other path after bracken has filled in. This marking would be required to ensure visitors don't stray off the sides and into ground with shearwater burrows.

Duty Officers would need to manage the mitigations very strictly, in the context of a deteriorating situation. This would be difficult as expectations would be high, based on previous visits, and requires a cultural change.

Option	1. Discontinue management
Management	Discontinue the habitat restoration programme.
Vegetation	Rapid reversion to a dense bracken cover. Loss of grassland habitat. Decreased species diversity. Perhaps increase of scrub/woodland over long term in absence of rabbits.
Soil	Development of deep Bracken litter horizon. Loss of grassland dense root-mat. Macronutrient sequestration in Bracken rhizomes.
Rabbit	Loss of grass forage area, reduced population size and capacity to recover after disease events. Less burrow creation.
Manx Shearwater	Reduced creation of new nesting burrows. Burrow integrity reduced as Red campion and Bracken cover increases. Increased frequency of collapse from visitors and ringers.
Mitigation	Prevent visitor access to areas with Manx Shearwater burrows. Limit monitoring to essential minimum. Implement access control via adaptive management over the short and medium terms to reduce negative impacts.
Uncertainty	High probability of dense Bracken development and increased negative impacts of ringing and walking over shearwater sub colony areas. Medium certainty of reduced Shearwater breeding success over the long term.
Issues	Unknown extent to which the development of dense Bracken stands will influence Manx Shearwater population survival over the longer term.
Resources	Financial recurrent cost-saving (ca., £1500-2000);
Implications for Observatory Management	Mitigations required for access and visitor activity in context of declining accessibility and path condition (slippiness, visibility) and Health and Safety. Eventual closure of the Observatory.

Option 2. Continue same level of restoration input as 2015 and before (restoration process approach)

The methods outlined in the 'Copeland Bird Observatory Mowing Manual' have been tried, developed, and proven over 19 years. Many lessons have been learned. H&S risk assessments are provided, along with assessments to ensure nesting birds are not disturbed. Frequency and method of mowing have been adapted over time to improve the efficiency and effectiveness of the treatment methods. As detailed in this document, management input reduced over time, and changes to the habitat quality, path specifications have been demonstrated.

Mitigations required are outlined in the Mowing Manual (McKee, 2016) and include an informed risk-based approach to carrying out mowing activities during the nesting season. The advantage of this approach is that operators can be informed of the sensitivities, but once mown, the paths become usable by all afterwards with reduced risk of disturbing nesting birds and collapsing burrows.

Option	2. Maintain current restoration programme
Management	Cut and remove biomass as in the 2015 restoration programme.
Vegetation	Progressive increased semi-natural grassland species richness developing in mid and late-stages of restoration.
Soil	Low surface soil macronutrient status and dense, fibrous grass root-mat developing in mid and late-stages of restoration.
Rabbit	Progressive increased area and palatability of rabbit forage giving a greater population carrying capacity.
Shearwater	Improved condition of nesting habitat: burrow integrity on managed areas more robust to trampling damage by visitors and ringers
Mitigation	Restrict access to areas with shearwater burrows in the early stages of restoration. Restriction not required on restored grassland areas, or areas with low cover of bracken or red campion.
Uncertainty	High probability of progressive restoration gains from late-stage grassland, species diversity, soil stability and Shearwater/Rabbit population resilience.
Issues	Volunteer and funding availability for sustaining protected species and habitat condition will be needed.
Resources	No change in recurrent funding, £1500-2000. More volunteers required to reverse restoration decline since 2015. Commitment to carry out restoration work from May to realise efficiencies and put mitigations in place for reducing disturbance to nesting birds. Remove financial disincentives for volunteers. Dedicated social media advertisements and website videos needed.
Implications for Observatory Management	Management continues as before, but with a pro-active recruitment drive for volunteers to carry out restoration work.

Option 3. Reduced restoration input (restoration process approach)

Reduced restoration input could mean one of two aspects:

1. Reducing the number of areas and paths treated. Removing paths from the mowing programme must be agreed within the Membership and with DAERA. The plan would identify essential paths that would continue to be managed, which help access the areas of the island that are required to maintain a minimum monitoring programme. Parts of the island would become inaccessible throughout the year. These would be most likely the areas with shearwater burrows present. Other areas could still be accessed in the winter, if there are no burrows present.

2. It could also mean reducing the frequency of treatments, for example as has happened since 2016, the first cut was carried out in July, not May.

   Starting treatments later in the season (July), rather than in late May, has the following results:

   - The first cut is harder for volunteers to complete as mowers do not cope very well with tall dense bracken. Raking this is an extra job and more time consuming.

   - Grasses and other finer species are suppressed for a significant proportion of the growing season (prior to cutting), leading to a regression in habitat quality.

   - Rabbit foraging habitat becomes unavailable at a time when foraging is required the most after the lean winter, and perhaps lowering breeding productivity.

- Paths tend to become narrower over time, as the edge is not clear to operators. The edge is easily identified in May due to the presence of previous years bracken litter.
- Paths are not visibly clear to follow, so visitors could stray onto fragile soils off the path.
- Higher vegetation growth on the paths means tern, gull, Oyster Catcher chicks would hide on the paths, will be harder to spot, and therefore have an increased probability of being trampled by visitors. This is likely on the paths from the Jetties, i.e. passage is essential for the running of the observatory.
- The time taken to walk through paths with taller vegetation is increased, as visitors would have to search behind shrubby plants, for chicks and check they will not stand on them when moving forward. The impact of this is that it takes longer to pass along the path, increasing the period of disturbance to the nesting birds.

Mitigations required would be similar to Option 1, but at a slower rate if change.

Option	3. Reduce restoration input
Management	Reduce the area and frequency of cut-remove seasonal management, as implememented in 2018.
Vegetation	Regression of species-rich grassland to Bracken and Tall-herb vegetation where management is reduced or discontinued.
Soil	Progressive reduced surface root-mat and increased macronutrient sequestration.
Rabbit	Reduced forage availability, leading to decreased population carrying capacity, robustness and resilience to disease.
Shearwater	Reduced condition of habitat (fledglings more likely to be trampled by ringers) and increased cumulative risk of burrow collapse in areas removed from management.
Mitigation	Prioritise cutting on paths in Shearwater areas with late-stage and intermediate-stage restoration status. Make the first cut before end of May to maximise the restoration impact.
Uncertainty	High probability of increased Bracken/Tall-herb cover, decreased area of grassland and decrease in rabbit and shearwater populations. Increased negative impacts of ringing and walking over shearwater sub colony areas
Issues	Restoration gains would be lost and there will be negative impact on volunteer morale. CBO/ DAERA communication process needed for restoration versus reduction decisions.
Resources	Minor reduction in recurrent resource commitment. Possible inefficiencies if not planned optimally, e.g. if no early work in May is carried out, this leads to extra work required later in season.
Implications for Observatory Management	The negative impact on access, visitor activities and expectations will be managed by CBO. Decisions on path priorities for continued management and access closure need DAERA agreement and assessment of impacts.

Option 4. Controlling bracken by cutting (species control approach) and leaving cutting in situ

The table below describes the various conclusions. Put simply, recycling nutrients and smothering desirable plants (by leaving cuttings in situ) will suppress desirable early successional plant species, and promote the vigour and spread of ruderals, such as red campion and bracken.

It was observed to be very counter-productive on the island during the 1980s and 1990s. Especially when piles of vegetation were left on existing grassy areas, which resulted in the establishment of red campion and bracken in the following years. Even small amounts left in the ecotone can have negative impacts when considered cumulatively over several years.

This is highly undesirable for objectives of habitats, valuable bird species, reducing impacts from visitors and access, and the running of the observatory. In addition, it locks volunteer effort into an ever increasing and demotivating requirement, using more resources year on year just the maintain the status quo.

Mitigations required. It is believed that Skomer and Skokholm provide access using this method. However, there are two major factors which are different on CBO, that would rule this out as a responsible option.

Firstly, CBO paths are on soil, whereas the main paths on Skomer appear to have a hard and stony foundation (similar to Big Copeland), perhaps as a result of the previously farmed fields, or the past use of mechanised vehicles (quads or tractors). This means that there are fewer burrows underneath, since they have already been disturbed, collapsed and are now absent.

Secondly, the proportion of the footprint of paths traversing sub colonies compared with the total area with burrows is higher on CBO. The impact on Shearwater burrows would be greater if this method was adopted, since the proportion of the total number of burrows of the colony made more vulnerable to collapse would be greater.

It should be noted that a mitigation measure used on Skomer and Skokhom to prevent burrow collapse is to rule that all ringers crawl on their hands and knees to access the burrows for monitoring and ringing purposes.

Option	**4. Cut and leave bracken**
Management	Control Bracken vigour by seasonal cutting without frond removal.
Vegetation	Bracken litter accumulation, increased vigour of tall-herbs (especially Red campion) and deterioration of access paths.
Soil	Increased depth of bracken litter layer, root-mat deterioration, and macronutrient release to the soil.
Rabbit	Reduced forage productivity and palatability, population robustness.
Shearwater	Reduced condition of habitat (fledglings more likely to be trampled by ringers) and increased cumulative risk of burrow collapse in areas removed from management.
Mitigation	Cut Bracken before mid-June and carry out a late season Tall-herb cut. Implement access control via adaptive management over the short and medium terms to reduce negative impacts.
Uncertainty	High probability of increased tall-herb cover; increased localised bracken litter, reduced grassland condition; path deterioration; slower soil condition improvement. Increased negative impacts of ringing and walking over shearwater sub colony areas
Issues	Early-stage and intermediate-stage Tall-herb control would be required.
Resources	Minor reduction in recurrent resource commitment in short term, but increases over medium and long terms.
Implications for Observatory Management	Managed decline of access and activities involves managing mitigations and visitor expectations and providing safety information for visitors (path condition, slippiness, and visibility deterioration). Continuing access for ringer and visits need to be assessed by DAERA on an ongoing basis, or a protocol agreed and implemented.

Option 5. Chemical control of bracken

An unintended consequence of chemical control (BCS 2005) would be easier access to controlled areas, allowing visitors to roam freely, risking damage to Manx Shearwater nesting sites and foraging areas.

Using pesticides on a designated site is regarded as an extremely undesirable action to take. It is usually only considered if there is no alternative remedy available.

Mitigations that would be required After treatment, early-stage vegetation development would be a high Red Campion ground cover as occurs in the Early-stage of Option 1 management. Visitors and ringers would have to be prevented from accessing areas and paths that have been treated so that burrows are not damaged. Implementing access restriction would involve preventing accessing treated. Signage and roping off areas may be needed, and maintained at each visit, all the year round.

Option	5. Treat bracken with herbicide
Management	Long-term Asulam or Glyphosate treatment of Bracken, with repeat treatments following bracken recovery and spot treatment as needed.
Vegetation	Partial frond death, reduced rhizome vigour and large macronutrient release into soil. Increased Tall-herb vigour. Toxicity to other plant other species. Reduction of grassland.
Soil	Soil eutrophication (especially nitrogen), facilitating Tall-herb biomass increase (especially Red campion). Micro-flora and fauna toxicity.
Rabbit	Possible toxicity by direct contact and indirectly from forage. Reduced forage productivity due to reduction of cover of palatable vegetation, leading to reduction in population robustness.
Shearwater	Toxicity by direct contact and from soil in nesting burrows. Reduced Burrow integrity from soil eutrophication. Reduced condition of habitat (fledglings more likely to be trampled by ringers)
Mitigation	Trial and monitor the impact on conservation features (especially species rich grassland and desirable species) and quality and impacts of access. Restrict spraying to areas outside the CBO water-well catchment. Prevent access to treated areas. Strict operational rules to be followed to reduce 'drift'.
Uncertainty	High probability of rapid herbicide toxicity and soil eutrophication. Unintended long-term ecosystem impact is uncertain. Availability of approvals is uncertain for Asulam on ASSI/SPA. Uncertainty of effectiveness and number of years of treatment required. High certainty of rapid recovery and spread of bracken after ceasing treatment.
Issues	Untrialled short-term/long-term impact on species-rich grassland, Shearwater and its nesting habitat. Reputational damage of herbicide use on protected site. Early-stage and intermediate-stage tall-herb control would be required.
Resources	Large funding increase for initial and repeat treatments and ecological monitoring. Potential reputational damage to DAERA and CBO. Operational problems: water volumes for application; limited dry/calm weather for application to reduce 'drift'; health/safety.
Implications for Observatory Management	Long term mitigations required to prevent access by ringers/visitors to Shearwater sites. See the other options for assessment of impacts.

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Appendices

1. Table of management options and implications

2. Interpretation of photography for estimating vegetation category cover from 1970s to present

3. Photographic analysis of vegetation changes in areas under restoration – 2 case studies

4. Comparison of quadrat photos from 2015 and 2018

5. Mowing records 2005 to 2015

These appendices are separate documents.