Responses of *Sphagnum austinii* and *S. beothuk* on Cors Fochno to significant habitat improvement

Des Callaghan, **Justin Lyons** and **Fred Slater** analyse changes in the frequency of two oceanic *Sphagnum* species

△ Figure 1. *Sphagnum austinii* at Cors Fochno. *Des Callaghan*

Across large areas of the world, exploitation of peatlands by humans has been unsustainable, leading to widespread destruction and degradation of these habitats. Peatland loss has been particularly acute in Europe, where only mineral soils now occur across 20% of the original habitat (i.e. all peat has been lost), and 44% of the remainder is no longer accumulating peat (Joosten, 2016). Raised bogs have been particularly affected and as a result are included on the European Red List of habitats (Janssen *et al.*, 2016). In the UK, only a very small portion (6%) of lowland raised bog

remains in a natural or near-natural condition, with loss and degradation especially caused by afforestation, peat extraction and agricultural intensification, including drainage (Littlewood *et al.*, 2010). In response, over the past few decades a lot of effort has been spent attempting to conserve and restore these habitats, often with a focus on improving hydrological regimes, but also including management to combat problems associated with over-grazing, invasive species, fires, pollutants and erosion (Gorham & Rochefort, 2003; Littlewood *et al.*, 2010; Schumann & Joosten, 2008).

Many species characteristic of raised bogs are threatened with extinction primarily because of habitat loss and degradation and require special conservation attention. In Wales, this includes *Sphagnum austinii* (Fig. 1) and *S. beothuk* (Bosanquet & Dines, 2011); the latter until recently was over-looked in Europe as a form of *S. fuscum* (Kyrkjeeide *et al.*, 2015). In fact, *S. austinii* is of significant conservation concern across Europe, being categorised as 'Near Threatened' on the current European Red List (Hodgetts *et al.*, 2019). Both species exhibit an oceanic distribution and in Wales are confined to just two sites, Cors Fochno (Cardiganshire) and Cors Goch Trawsfynydd (Merionethshire). Populations at the former are much larger than at the latter. The special importance of Cors Fochno for the future of these species in Wales is recognised within the current management plan for the site, which includes the following Conservation Objective: 'The rare hummock forming bog mosses *Sphagnum austinii* and *S. beothuk* will have stable or increasing populations'. The aim of this study is to determine trends in the populations of *S. austinii* and *S. beothuk* at Cors Fochno, and their current population sizes, following a period of significant habitat improvement.

Method

Study site

Cors Fochno (Fig. 2), also known as Borth Bog, is a large coastal peatland adjacent to the Dyfi Estuary, in Cardiganshire (vc 46). It is included within various statutory protected areas, including Cors Fochno Special Area of Conservation, Dyfi Biosphere Reserve, Dyfi National Nature Reserve, and Dyfi Site of Special Scientific Interest. The climate is oceanic, with 160 rain days a year and average temperatures of 15.6°C during the hottest month (July) and 5.0°C during the coldest month (February) for the period 1961–2002 (Met Office data supplied through the UK Climate Impact Programme). Atmospheric nitrogen deposition is relatively low, estimated to be 7.3 kg N ha^{-1} yr^{-1} for the period 2016–2018 (APIS, 2020). The central dome has never been cut-over, but marginal areas were cut for peat historically, a practice that ceased over 100 years ago. Habitat conditions on the primary mire, to which *Sphagnum austinii* and *S. beothuk* are confined, have significantly

▽ Figure 2. Location of Cors Fochno. Satellite image © Google, DigitalGlobe.

△ Figure 3. Example of a random 100 m plot at Cors Fochno. *Des Callaghan*

improved in recent decades owing to two main factors. Firstly, burning of marginal *Molinia caerulea* and *Phragmites australis* by local farmers formerly occurred each spring, and every few years a fire would spread uncontrolled across the primary mire (Benoit, 1960; Slater, 1974). This practice had ceased by the late 1970s, although there was a large accidental fire in 1985 that burnt about two-thirds of the site. Since then, there have been no major fires. Secondly, owing to ongoing conservation actions that began in the late 1980s, restoration of the hydrology has occurred across large parts of the site by the damming of drainage ditches and peat cuttings, providing partial restoration of the water table and significantly wetter habitat conditions.

Permanent plot

In 2001, a 600 × 200 m plot was established for the purpose of monitoring abundance of *S. austinii* and *S. beothuk* (Newton, 2001), hereafter termed the permanent plot. The plot is aligned with the Ordnance Survey (OS) grid and comprises a large portion of the best quality ombrotrophic mire habitat at Cors Fochno. Following the same method as Newton (2001), the plot was re-monitored in 2020. This involved walking at a slow pace whilst searching for the two target species, following transverse transects across the plot each *c.* 5 m apart. Location coordinates were collected for each hummock found, logged with a hand-held GPS unit (Garmin GPSMAP 64s), which consistently reported an accuracy of ≤3 m during the present survey conditions. The maximum length and breadth of each hummock were also measured. Subsequently, hummock size was calculated as the basal area (cm^2) of a hummock, approximating an oval ($\pi \times (l/2) \times (w/2)$), where l = maximum length of hummock and w = maximum width of hummock, following Yabe & Uemura (2001). The differences in the average sizes of hummocks of *S. austinii* and *S. beothuk* between 2001 and 2020 in the permanent plot were tested statistically. The data deviated significantly from a normal distribution, indicated by a Shapiro-Wilk test, and so a Mann-Whitney-Wilcoxon test was used.

Random plots

A total of 170 OS 100 m grid cells overlap the primary mire habitat of the site. In 2020, a random sample comprising 32 of these grid cells was visited (Fig. 3), excluding the 12 within the permanent plot. A timed one-hour survey was conducted within each, searching for colonies of *S. austinii* and *S. beothuk*. When found, survey time was paused whilst identity was checked, location coordinates logged, and hummock size measured.

Historic locations

For *S. austinii*, all locations on Cors Fochno where the species has been reported previously, including those documented by Slater (1974), were revisited and a search undertaken for the species. When found, GPS locations were collected and hummock size measured.

Population estimates

An overall estimate of the number of hummocks

plus 95% confidence intervals was derived by: (i) calculating the mean number of hummocks across the 32 random plots; (ii) calculating 95% confidence intervals for the mean by multiplying the standard error by 1.96; (iii) multiplying the mean and confidence intervals by 154 (i.e. the number of OS 100 m grid cells which overlap the primary mire, excluding the 12 within the permanent plot); and (iv) adding the number of hummocks within the permanent plot to the result.

Results

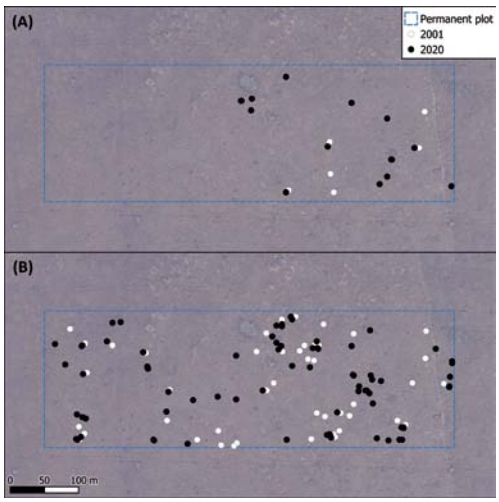
Permanent plot

Locations of hummocks of *S. austinii* and *S. beothuk* within the permanent plot in 2001 and 2020 are shown in Fig. 4, and a boxplot of the size of hummocks is shown in Fig. 5. *Sphagnum austinii* is rare but shows a 114% increase in the number of hummocks between 2001 and 2020, from 7 to 15, and a 265% increase in the summed area of all hummocks, from 5443 to 19,849 cm^2. The average size of *S. austinii* hummocks increased from 777 cm^2 (range 276–1495) to 1323 cm^2 (range 82–4656), though because of the small sample size this is not statistically significant (W = 48, p = 0.783). There was a 38% increase in the number of hummocks of *S. beothuk* during 2001 to 2020, from 60 to 83, and a 192% increase in the summed area of all hummocks, from 5.1 to 15 m^2. The average size of *S. beothuk* hummocks underwent a 111% increase, from 858 cm^2 (range 110–4893) to 1812 cm^2 (range 38–8482), which is statistically significant (W = 1493, p <0.01).

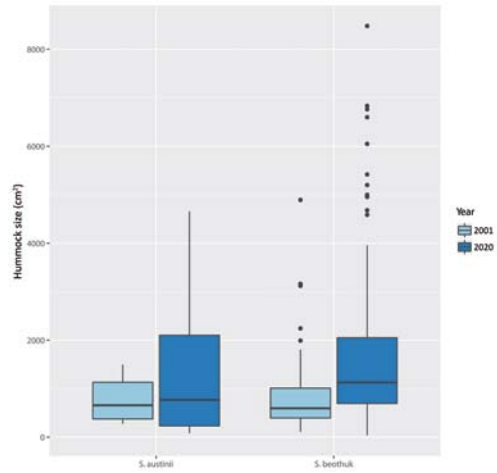
Random plots

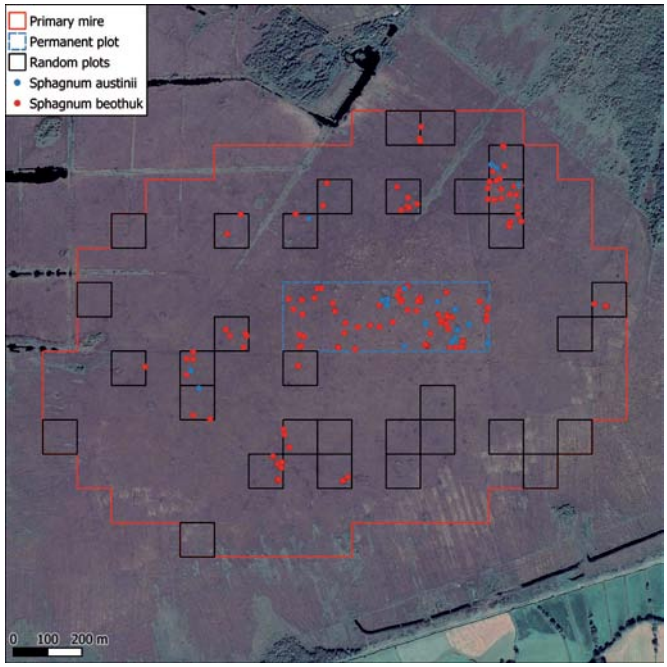
Locations of hummocks of *S. austinii* and *S. beothuk* within the random plots in 2020 are shown in Fig. 6. The former was rare, with only eight hummocks found, averaging 0.25 hummocks per plot (range = 0–3), with a mean size of 999 cm^2 (range = 236–3101). *Sphagnum beothuk* was relatively frequent, with a total of 99

▽ Figure 4. Locations of hummocks of (A) *Sphagnum austinii* and (B) *S. beothuk* within the permanent sample plot at Cors Fochno in 2001 and 2020. Satellite image © Google, DigitalGlobe.



▽ Figure 5. Boxplot of size of hummocks of *Sphagnum austinii* and *S. beothuk* in 2001 and 2020 within the permanent sample plot at Cors Fochno.





△ Figure 6. Locations of hummocks of *Sphagnum austinii* and *S. beothuk* within all sample plots at Cors Fochno in 2020. Satellite image © Google, DigitalGlobe.

hummocks found, averaging 3.1 hummocks per plot (range = 0–17), with a mean size of 1955 cm^2 (range = 86–15161).

Population estimates

The total population estimate for *S. beothuk* throughout Cors Fochno is 559 hummocks, with the 95% confidence intervals indicating a range between 341 and 778. A population estimate plus confidence intervals is not possible from the data for *S. austinii* because of its rarity and the large amount of unsurveyed potential habitat. However, a total of 59 hummocks of *S. austinii* were found in 2020, including those within the permanent plot (15), random plots (9) and elsewhere (35).

Discussion

This study shows that a large population of *S. beothuk* presently occupies Cors Fochno and that during 2001–2020 it underwent a significant increase. The period coincides with two key environmental changes that have improved habitat conditions of the primary mire, namely cessation of fires and partial restoration of the water table. Prescribed burning of heathland is known to significantly impact survival and growth of *Sphagnum* (Noble *et al.*, 2019) and the elimination of fires at Cors Fochno is likely to have been especially beneficial. Also, whilst hummock-forming species such as *S. beothuk* exhibit relatively high water loss resistance (Bengtsson *et al.*, 2020; personal observation), the wetter habitat conditions will no doubt have been an important benefit by reducing the frequency and length of periods of desiccation. Regarding *S. austinii*, the situation is curious. Slater & Slater (1978) documented a large population of this species at Cors Fochno in 1973, with 168 hummocks in a 16 ha area of the mire. By 1977, following a severe fire in 1974, there were only 39 hummocks in this area (Slater & Slater 1978), in 1992 there were two (Hale 1992) and in 2000 there were six (Newton 2000). Results of the present study show the population of *S. austinii* across Cors Fochno remains small, though a modest increase from 2001 appears to have occurred. Thus, the former large population has not become re-established, even after a prolonged period of improved habitat conditions and at a time when the ecologically similar *S. beothuk* has increased

substantially. Reasons are unclear and deserve further investigation. This could usefully include long-term and detailed monitoring of a sample of *S. austinii* and *S. beothuk* hummocks of various sizes to determine key factors related to hummock survival and mortality, such as their relation to seasonal water-table position, severe weather events (e.g. prolonged droughts) and competitive exclusion. Large-scale works are presently being undertaken at Cors Fochno to further restore the water table and so it will be especially interesting to see how populations of *S. austinii* and *S. beothuk* respond in the future.

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