

The unusual inter-tidal niche of the rare moss *Bryum marratii*

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Abstract

This is the first detailed ecological investigation of the rare moss *Bryum marratii*. Results show occupancy of a niche at the two study sites that is unusual amongst bryophytes, within the upper edge of saltmarsh. All colonies ($n=120$), which comprise the largest populations in Wales, occur in an elevation zone of just 57 cm and are subject to frequent inundation by higher spring tides. In total, the average location of a *B. marratii* colony was submerged by seawater 3.6 day⁻¹ yr⁻¹. Sea level rise, projected in the study region to be 30-46 cm during the current century, is a major threat to the long-term survival of these populations.

Keywords:

Spring tides, saltmarsh, sea level rise, salt tolerance

Introduction

Bryum marratii Wilson (Bryophyta: Bryaceae) is a moss of high conservation concern in Britain, listed as ‘Vulnerable’ on the UK Red Data List (Hodgetts, 2011), ‘Endangered’ on the Welsh Red Data List (Bosanquet & Dines, 2011) and considered to be of principal importance for conservation under Section 7 of The Environment (Wales) Act 2016. It is categorised as ‘nationally rare’ (Pescott, 2016) and was recorded from only 11 10 x 10 km Ordnance Survey grid cells during 1990-2013 (Blockeel *et al.*, 2014). Elsewhere in Europe, the species is generally rare, being a candidate for inclusion in the forthcoming European Red Data List and known mainly from north-western countries: Denmark, Estonia (Vulnerable), Finland (Endangered), France, Germany (Critically Endangered), Iceland, Ireland, Latvia, The Netherlands (Vulnerable), Northern Ireland (Extinct), Norway (Near-threatened), Poland (Extinct), Slovakia (Critically Endangered) and Sweden (Near-threatened) (Lockhart *et al.*, 2012; Hodgetts, 2015; N.G. Hodgetts, pers. comm.). Outside Europe, it is reported only from the Altai Mountains (north-central Asia) and very locally in North America, plus an unusual occurrence in Yemen (Lockhart *et al.*, 2012).

The complex ability to endure salt concentrations approaching those of seawater is an unusual trait amongst land plants (Flowers *et al.*, 2010). This is reflected by habitat occupancy amongst bryophytes, whereby saltmarsh is a normal habitat for only 14 (1.3%) species in Britain and Ireland (Hill *et al.*, 2007), amongst them *Bryum marratii*. Perhaps because large parts of saltmarshes usually lack any bryophytes, this habitat has been ignored by bryologists, with very few published studies (Adam, 1976; Garbary *et al.*, 2008; Zechmeister, 2005). Likewise, the ecology of *B. marratii* is virtually unstudied, the very brief examination of habitat occupied at an inland saltmarsh in Slovakia (Šoltés *et al.*, 2010) perhaps based on a blunt-leaved form of *B. pseudotriquetrum* (formerly known as *B. neodamense*). Given the species is of conservation concern, it is important to gain a better understanding of its habitat requirements. The purpose of the present study is to provide such, specifically regarding the tidal characteristics of occupied locations.

Materials and Methods

Study sites

The study sites comprise two coastal saltmarshes in Carmarthen Bay, South Wales (Figure 1), at Pembrey Burrows (51°43'01.8" N, 4°20'18.9" W) and Whiteford Burrows (51°37'48.6" N, 4°14'46.3" W). The climate is oceanic, with 150 rain-days yr⁻¹ (days with >1 mm rain) and average temperatures of 15.7°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). Both saltmarshes are within riverine estuaries and have developed behind sand dune spits, which provide shelter from the open sea. The site at Pembrey is within Pembrey Coast Site of Special Scientific Interest (SSSI), and that at Whiteford is within Whiteford Burrows, Landimore Marsh and Broughton Bay SSSI and Whiteford National Nature Reserve (NNR). Both are within Carmarthen Bay and Estuaries Special Area of Conservation (SAC). These two saltmarshes support the largest populations of *Bryum marratii* in Wales, possibly in Britain. The moss was first found at Pembrey in April 2013 (Bosanquet, 2013) and at Whiteford in April 2012 (Bosanquet, 2012).

Locations of Bryum marratii colonies

A detailed search for colonies of *Bryum marratii* was undertaken on 30 April 2017 (Pembrey) and 1 May 2017 (Whiteford). Once found, the location (x-, y- and z-coordinates) of each colony was recorded with a Leica Viva GS14 GPS (Leica Geosystems, Heerbrugg, Switzerland). The general distribution pattern of colonies at both sites had not changed significantly from that reported and photographed by Bosanquet (2012, 2013).

Tidal inundation

The nearest tide gauge to the study sites is the British Oceanographic Data Centre (BODC) gauge at The Mumbles (51°34'12.0" N, 3°58'31.6" W), located in nearby Swansea Bay (Figure 1). Tide level data from this gauge, logged every 15 mins, was accessed for 1 January 2010 to 9 June 2014. The initial dataset included 155,591 measurements, from which 35,112 (23%) were excluded because they were marked as 'improbable' by quality control at BODC. The final dataset of 120,484 values was used to provide estimates of the frequency, duration and timing of tidal inundation events at locations occupied by *B. marratii* colonies. Inundation of the lowest colony of *B. marratii* at Whiteford Burrows was observed in the field during a high spring tide on the morning of 26 May 2017, when a sample of water that covered the colony was collected. The water sample was stored in a freezer before being transported to a laboratory where pH and electric conductivity (EC) were measured, the former with a Thermo Orion 720A probe (Thermo Fisher Scientific, Waltham, USA) and the latter with a Mettler Toledo SevenMulti instrument (Mettler Toledo, Zaventem, Belgium), according to United Kingdom Accreditation Service (UKAS) standards.

Data analysis

Statistical analyses were undertaken in R (R Core Team, 2017). A Welch Two Sample t-test was conducted to compare elevation of colonies between the two study sites. Spatial analyses and mapping were undertaken in Quantum GIS (Quantum GIS Development Team, 2017).

Results

Locations of Bryum marratii colonies

A total of 120 colonies of *Bryum marratii* were found, 76 along 234 m of upper saltmarsh at Pembrey and 44 along 680 m of upper saltmarsh at Whiteford (Figure 2). Each colony comprised a small tuft of erect shoots, 1-5 cm diameter. Sporophytes were not seen, but deciduous shoot tips were frequent. Location coordinates of colonies (Appendix 1) had a mean horizontal accuracy of 0.78 cm (range = 0.50-6.2 cm) and a mean vertical accuracy of 1.2 cm (range = 0.8-3.2 cm). Of 75 occupied OS 1 x 1 m grid cells, the majority ($n=52$; 69%) contained only a single colony (Figure 3). The largest cluster of colonies was at Pembrey (Figure 4), where up to six colonies were present in a single OS 1 x 1 m grid cell. There was a small but significant difference in the elevation of *B. marratii* colonies between sites, those at Pembrey ($\bar{x}=4.70$ maOD, s.d.=0.056, $n=76$) on average 7.1 cm lower than those at Whiteford ($\bar{x}=4.77$ maOD, s.d.=0.082, $n=44$); $t(66.95)=-5.06$, $p<0.01$. Across the two sites, all colonies ($n=120$) occur in an elevation range of 0.57 m (4.42-4.99 maOD), reduced to just 0.32 m when the two most extreme outliers are omitted (4.56-4.88 maOD; $n=118$).

Tidal inundation

Tide levels ranged across 10.61 m (-4.88-5.73 maOD) within the study areas. All *Bryum marratii* colonies are within this inter-tidal zone, limited to a narrow upper part. Here, they are inundated many times, 32-128 events yr⁻¹, during ‘spring tides’, when tidal bulges formed by the sun and moon coincide to produce the highest tides (Table 1; Figure 5). Spring tides are clustered around two periods each month, during ‘new moon’ and ‘full moon’ lunar phases, though not all produce inundation events; of the 88 studied, 59 (67%) produced tides high enough to submerge, at least, the lowest *B. marratii* location (Figure 5). The site of the lowest colony experienced the longest tidal inundation event, 3 hr 15 min, on 3 January 2014, when water depth reached 131 cm. On average, each location of a *B. marratii* colony was submerged 3.6 day⁻¹ yr⁻¹ (range = 1.3-8.1). Water that inundated the lowest colony at Whiteford on 26 May 2017 had pH = 7.41 and EC = 5.44 S/m (at 25 °C).

Discussion

This is the first detailed study of any aspect of the ecology of the rare moss *Bryum marratii*. Results show occupancy of a niche at the study sites which is unusual amongst bryophytes, at the upper edge of saltmarsh. All colonies of the moss, which comprise the largest populations in Wales, are subject to frequent inundation by higher spring tides, within a very narrow elevation zone, just 57 cm. EC of water that inundated the lowest colony at Whiteford on 26 May 2017 is typical of surface seawater in the region of the British Isles (Tyler *et al.*, 2017), suggesting salinity was not substantially reduced by local freshwater inputs. However, further data on water salinity during inundation events are desirable, including direct measures of salinity. Very few other bryophytes occur close to the moss, limited to occasional small patches of *Didymodon tophaceus* and *Henediella heimii*. Above the *B. marratii* zone, extensive mats of the large pleurocarpous moss *Calliergonella cuspidata* become dominant, where absence of the smaller moss may be due primarily to competitive exclusion. Below the *B. marratii* zone, limited tolerance of tidal inundation could explain its absence.

Observations in Britain and Ireland suggest *Bryum marratii* is often associated with freshwater flushing onto upper saltmarshes (Bosanquet, 2012, 2013; Lockhart *et al.*, 2012; Blockeel *et al.*, 2014). The habitat of the moss at Whiteford lies adjacent to a dune aquifer, a simple groundwater dome created by direct rainfall recharge, which discharges onto the upper saltmarsh (Stratford *et al.*, 2012). The saltmarsh at Pembrey likewise borders a dune aquifer that discharges onto the marsh. At the time of the present fieldwork, visible surface water seepages from the aquifers were very localised and whilst some colonies of *B. marratii* grew along such flushes, most colonies were not

clearly associated with aquifer discharge. However, diffuse discharge, which may not become visible as seepage lines, could be important.

Areas of saltmarsh occupied by *Bryum marratii* at Pembrey and Whiteford are heavily grazed by cattle and ponies, respectively. Grazing appears to be important for creating open patches of soil that may be colonised by the moss and for preventing competitive exclusion by larger species. Indeed, the species appears to have been lost from its only locality in Northern Ireland because of cessation of grazing at saltmarsh edges, and lack of grazing leading to dense grass cover along upper saltmarsh currently threatens several other Irish populations (Lockhart *et al.*, 2012). Similarly, at Morfa Harlech, Wales, where grazing by cattle is relatively light, colonies of *B. marratii* discovered in September 2015, which had colonised soil exposed along wheel ruts through a foredune slack (Holyoak, 2015), were all lost by November 2017 due to competitive exclusion by the mat-forming grass *Agrostis stolonifera* L. (Callaghan, 2017).

Whilst this work provides important new insights into the niche occupied by *Bryum marratii*, further study is clearly required, to gain a better understanding of its habitat requirements and conservation needs. This is especially important when considering sea level rise, projected in the region to be 30-46 cm during the current century (Lowe *et al.*, 2009) and presenting a major risk to the long-term survival of the populations investigated.

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Appendix 1. Location coordinates of *Bryum marratii* colonies

Data for each location presented as 'easting, northing (horizontal accuracy), altitude (vertical accuracy)', with horizontal measures as Ordnance Survey National Grid reference system and vertical measures as m a.s.l. Horizontal and vertical accuracies are derived by the Leica Viva GS14 GPS unit, such that there is at least a two third probability that the computed position deviates from the true position by less than the value indicated.

Pembrey: 238447.53, 204635.99 (0.0082), 4.7451 (0.0111); 238448.48, 204635.35 (0.008), 4.755 (0.0114); 238449.64, 204634.46 (0.0106), 4.6559 (0.0161); 238449.92, 204636.46 (0.0099), 4.7512 (0.0142); 238449.94, 204636.63 (0.0097), 4.6588 (0.0141); 238450.48, 204634.12 (0.0114), 4.7566 (0.0189); 238451.95, 204635.23 (0.0088), 4.6624 (0.0134); 238452.23, 204635.77 (0.009), 4.7547 (0.0149); 238452.73, 204644.13 (0.0081), 4.6876 (0.0121); 238452.82, 204635.62 (0.0086), 4.6492 (0.0138); 238452.82, 204644.4 (0.0069), 4.687 (0.0102); 238457.11, 204636.23 (0.0084), 4.7438 (0.0117); 238457.13, 204636.2 (0.0084), 4.7619 (0.0129); 238461.44, 204640.24 (0.0074), 4.7247 (0.0105); 238461.45, 204639.89 (0.0085), 4.7411 (0.012); 238462.73, 204640.7 (0.0069), 4.7614 (0.0101); 238462.81, 204640.28 (0.0077), 4.7294 (0.0112); 238462.89, 204640.31 (0.0081), 4.7296 (0.0116); 238462.94, 204640.13 (0.0079), 4.7497 (0.0114); 238492.01, 204602.57 (0.0061), 4.7737 (0.0114); 238495.88, 204613.05 (0.0067), 4.6997 (0.0125); 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Table 1. Tidal inundation of *Bryum marratii* colonies.

Colony height	Inundation frequency (inundation ⁻¹ yr ⁻¹)	Length of each inundation (hr)		Depth of each inundation (cm)		Total inundation time (day ⁻¹ yr ⁻¹)
		Mean	Max.	Mean	Max.	
Lowest (4.42 maOD)	128	1.52	3.25	37.5	131.2	8.1
Average (4.72 maOD)	69	1.26	2.75	27.0	100.8	3.6
Highest (4.99 maOD)	32	0.99	2.25	18.3	74.3	1.3

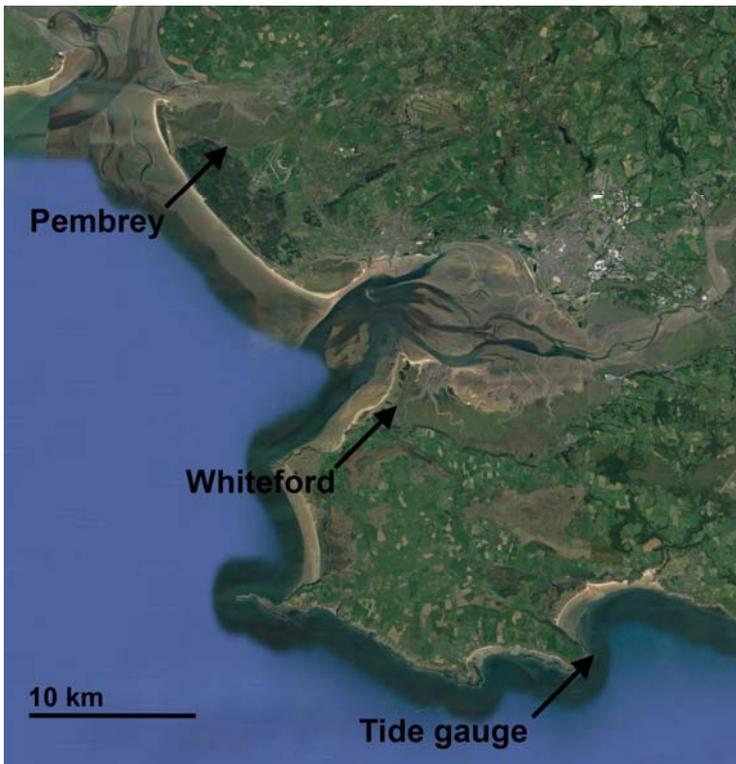


Figure 1. Location of study sites. Satellite image © 2017 Google, DigitalGlobe.

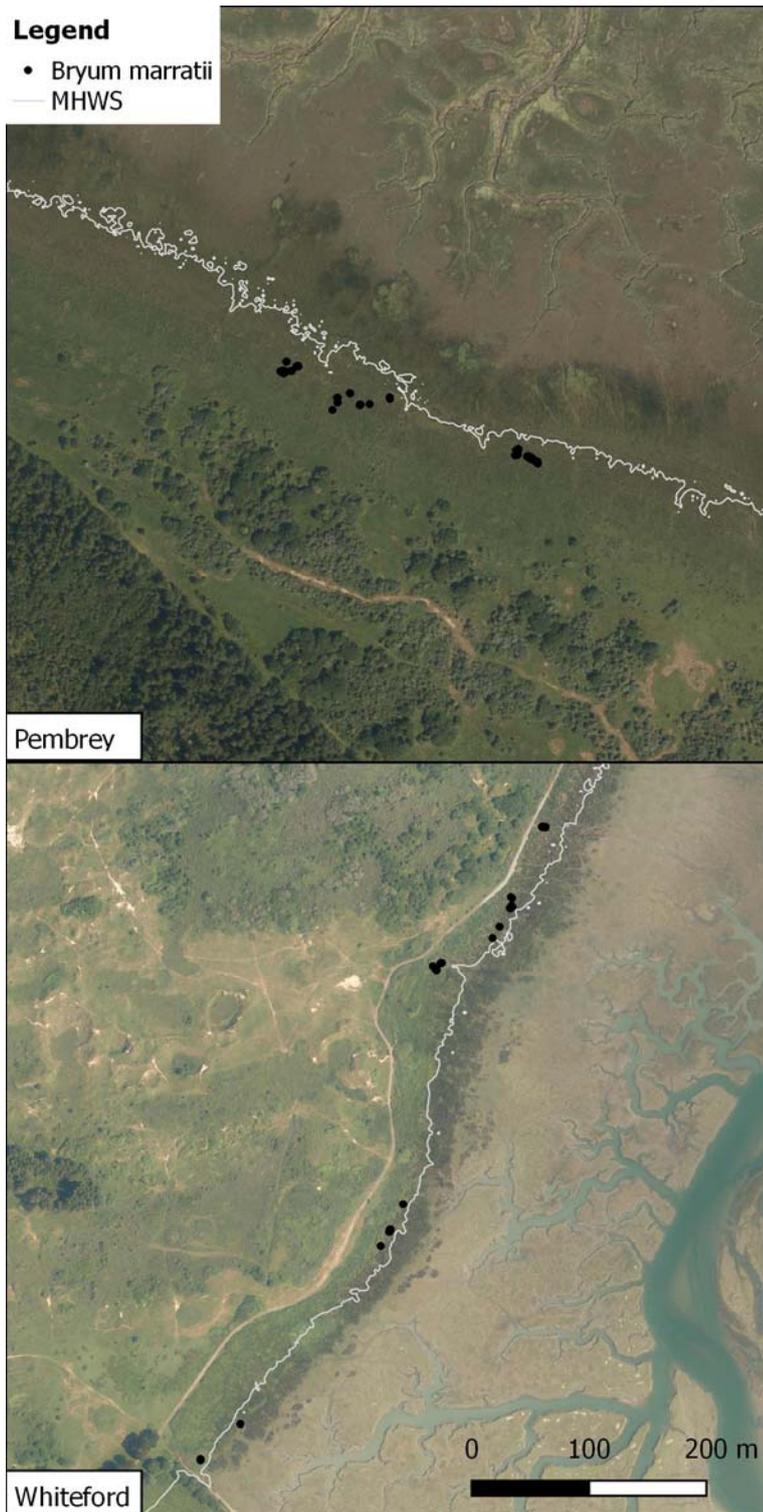


Figure 2. Distribution of *Bryum marratii* colonies. The predicted Mean High Water Spring tide for 2008-2016 (4.54 maOD) is indicated, obtained from The National Tidal and Sea Level Facility, The National Oceanography Centre (NOC). Satellite image © 2017 Google, DigitalGlobe.

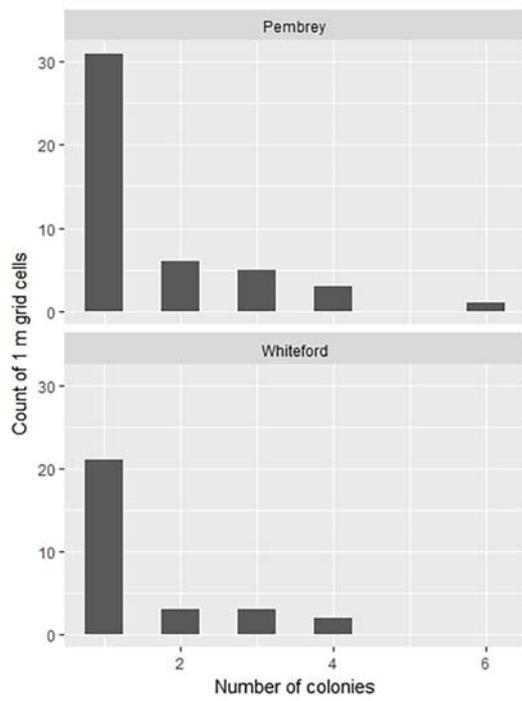


Figure 3. Frequency distribution of counts of *Bryum marratii* colonies within OS 1 x 1 m grid cells.



Figure 4. Flagged *Bryum marratii* at the largest cluster of colonies, on upper saltmarsh at Pembrey.
Photo: D.A. Callaghan.

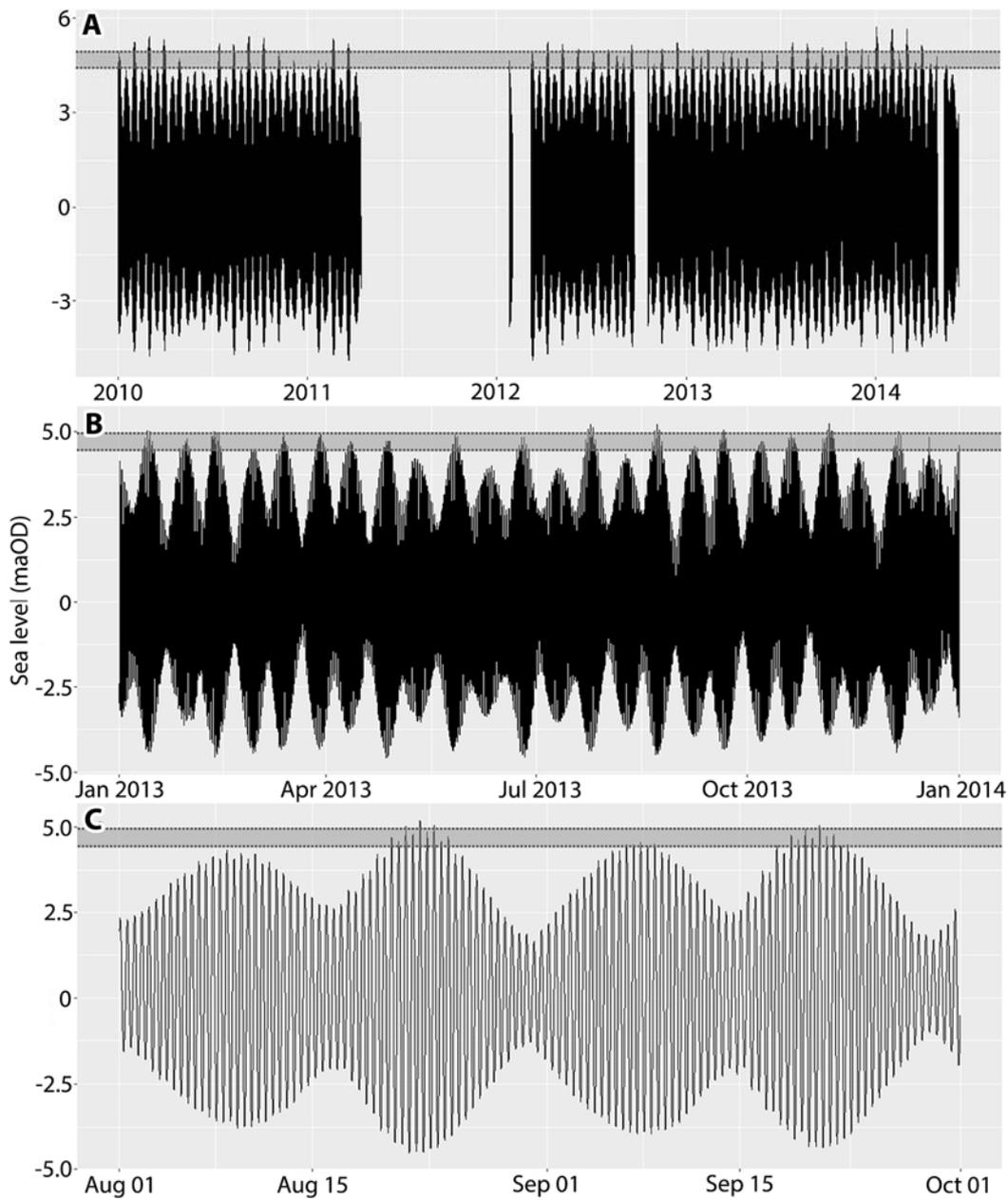


Figure 5. Elevation zone of *Bryum marratii* (grey band) and tide levels during (A) January 2010 to June 2014, (B) January to December 2013 and (C) August to September 2013. Tide level values considered 'improbable' by BODC are omitted.