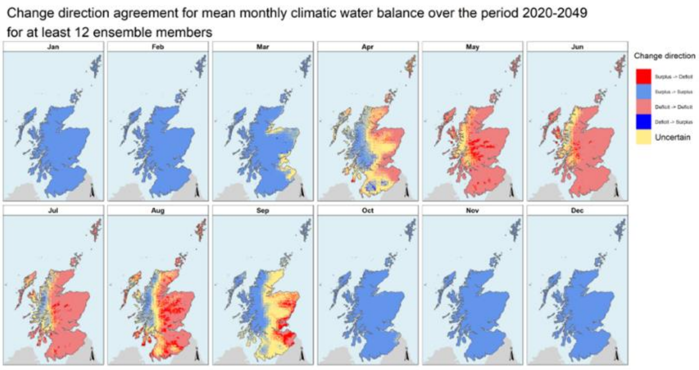
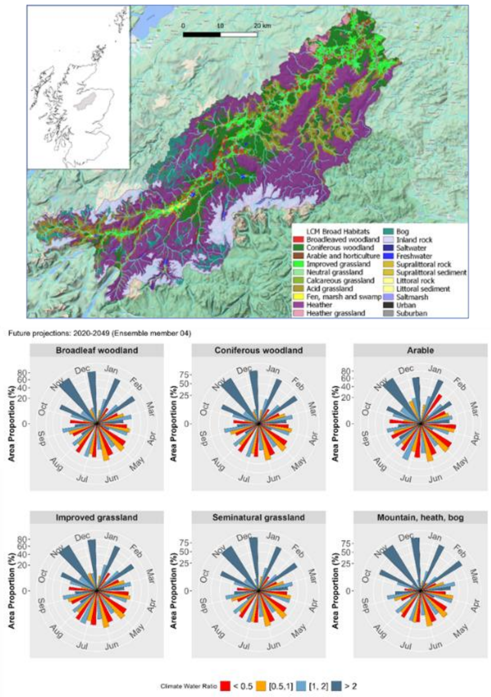
Assessment of Natural Capital asset exposure to current and future meteorological drought

Deliverables 2.1d and 2.3c for the

Project D5-2 Climate Change Impacts on Natural Capital

September 2023





Summary

This report is a product of the Scottish Government Strategic Research Programme project JHI-D5-2 'Climate Change Impacts on Natural Capital'. This is a joint report for Deliverable 2.1d: "Drought risk" and Deliverable 2.3c: "Assessment of habitat maps for distinguishing between high and low risk habitats". The purpose of this report is to assess exposure levels of Scotland's Natural Capital assets, to the threat of meteorological drought expressed by the Climatic Water Balance (difference between precipitation and reference evapotranspiration), as calculated in Deliverable 2.1a (Rivington and Jabloun, 2022).

The aim of this report is to provide assessments of the exposure of Natural Capital assets, expressed as mapped habitat types, to meteorological drought for observed (1990 – 2019) and future projected (2020 – 2049 and 2050 – 2079) Climatic Water Balance. This work builds towards the development of the Risk and Opportunities Assessment Framework (ROAF) being developed within the D5-2 project, in relation to the assessment of meteorological drought threat as part of the concept 'Risk as a function of Vulnerability, Exposure and Threat (R=VET)' (see Deliverable D1.5). We provide a national assessment using the spatial distribution of main habitat types in relation to the direction in Climatic Water Balance change. We also present an improved quantitative assessment of exposure severity using Climatic Water Balance ratios in a case study in the Spey catchment.

Key Messages:

- At a national level, observed shifts mainly from water surpluses to water deficits in late summer and early autumn are the main drivers of the degree of exposure for most habitat types, depending on their spatial distribution.
- Arable land and to a lesser extent improved grasslands and broadleaf woodlands are the most exposed habitat types to climatic water stress.
- Monthly Climatic Water Balance, although it exhibits large seasonal and spatial variation, is overall wetter for seminatural grasslands, heather moorlands, and peatlands, and to a lesser extent conifers, but it is of concern that water stress extends to early spring and late summer because of the potential and substantial impacts on their ecological and hydrological functions.
- Climatic Water Balance ratios can be used to assess exposure levels to climatic water stress and provide direct comparisons between different time periods for a given Natural Capital asset.

Advances in Technical Capabilities

This report has been developed through technical advances made in the JHI-D5-2 Project related to advanced geospatial processing for the joint analysis of habitat type and climatic data layers, and to visualisation techniques for improved presentation and dissemination of the results of this complex analysis.

Contents

Citation:

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https://www.hutton.ac.uk/sites/default/files/files/Assessment%20of%20Natural%20Capital%20asset%20exposure%20to%20current%20and%20future%20meteorological%20drought%20-%20Report%20D21d%20D23c.pdf

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Introduction

This is a joint report that combines results from Deliverable 2.1d: “Drought risk” and Deliverable 2.3c: “Assessment of habitat maps for distinguishing between high and low risk habitats”. The purpose of this report is to assess exposure levels of individual Natural Capital (NC) assets to the threat of meteorological drought for observed (1990 – 2019) and projected future periods (2020 – 2049 and 2050 – 2079). In this context, exposure represents the locations or areas covered by NC assets at risk of potential loss or that may suffer damage from the impact of meteorological drought (Chuvieco et al., 2023). Exposure forms a link between a given climatic-related threat or danger and the asset’s vulnerability. Hence, the exposure assessment presented in this report contributes to the developing the approach that “Risk as a function of Vulnerability, Exposure and Threat (R=VET)” that forms the basis of the Risk and Opportunities Assessment Framework (ROAF) being developed in the D5-2 project.

This work builds on results from Deliverable D2.1a: “Climate Trends and Future Projections in Scotland” (Rivington and Jabloun, 2022) and in particular on the calculation of the direction of change of Climatic Water Balance (CWB), where CWB is defined as the difference between Precipitation and Reference Evapotranspiration.

Meteorological drought is defined on the basis of the degree of dryness (in comparison to a baseline period) and the duration of the dry period and is considered to be region specific since the atmospheric conditions that result in deficiencies of precipitation can be highly variable. Hence, CWB provides a measure of meteorological drought that is relevant to climatic conditions in Scotland.

We spatially overlaid the generated data layers of calculated classes of direction of change of CWB at a spatial resolution of 1km grid cell with the broad habitat types from CEH’s Land Cover Map (LCM) for 2020 (Morton et al., 2021) at 10m grid cells. We used LCM 2020 because we have previously assessed it in Deliverable 2.3a: “Habitat Data layer for Natural Capital assessments” (Gagkas et al., 2023) and found that it is an appropriate land cover map for representing the spatial distribution of NC assets in Scotland. We then selected all CWB 1km grid cells with at least one 10m grid cell of aggregated LCM broad habitats and calculated proportions of 1km grid cells within the four (4) classes of direction of change in CWB (representing either climatic water surpluses or deficits) by each aggregated habitat type for the current and future climatic projections.

A limitation of this approach is that it provides the direction of change but not the magnitude of the actual change in climatic water availability. For example, although an area may remain at surplus or deficit, it is possible that the amount of deficit or surplus may also increase or decrease. We explored improving the exposure assessment in a case study in the Spey catchment by assessing exposure levels (such as severity) using CWB ratios, defined as the ratio of Precipitation to Reference Evapotranspiration, and conducting the same spatial overlays with LCM 2020 habitats as in the national assessment. Using a catchment case study made it easier from a processing perspective to trial and test this approach, and also helped with more easily identifying strengths and weaknesses of this approach.

Advancing analytical capability

Work presented here has advanced our technical analytical capability by:

- Developing scripts in R for advanced geospatial analyses. Due to the need for processing power for running these analyses, they were implemented using the available high performance computing facilities.

- Developing new visualisation approaches for creating plots and graphs to effectively present and compare the quite complex results related to the different combinations between habitat type and CWB metrics for current and future climatic scenarios.

Methods and Results

National assessment

Climatic water balance

Climatic Water Balance (CWB) is defined as the difference between precipitation input (P) and reference evapotranspiration (ET_o) output. Evapotranspiration is the total amount of moisture returned to the atmosphere from evaporation from surfaces and water transpired from plants and was calculated using the Priestly-Taylor method using precipitation, maximum and minimum temperature, and solar radiation (Rivington and Jabloun, 2022). Hence, CWB provides a metric of the combined impacts of changes in temperature and precipitation on water availability and its limitation that can lead to the occurrence of meteorological drought.

CWB was calculated on a monthly basis using P and ET_o to calculate CWB for each year of the observed (1960-1989 and 1990 – 2019) and projected future periods (2020 – 2049 and 2050 – 2079) and each 1km grid cell. Then averages were calculated for each period and the two CWB classes were determined (mean CWB <0, deficit and mean CWB ≥ 0, surplus). The calculated direction of change in CWB between the different time periods and the baseline period (1960-1989) indicate potential differences in water availability (Figure 1). Below a summary is given of these trends based on the findings of Rivington and Jabloun (2022):

Observed trends:

- There has been an observed change in CWB compared to the baseline period of 1960-1989, which is variable both spatially and temporally.
    - West coastal areas have become wetter (increased surplus water) between December to April.
    - Eastern Scotland has experienced a decrease in water availability between March to May, as has the whole of Scotland in September.
    - June to August have experienced an increase in CWB (precipitation is greater than evapotranspiration).

Projected changes:

- Projections show that there may be a shift in where and when parts of Scotland have a surplus or deficit of water.
- A key finding is that some upland areas of central Scotland are projected to shift from water surplus to deficit (Figure 1).
    - Most notably this is seen in May for the central Highlands and in August in the eastern and southern upland areas plus southern Argyll, Islay and Jura and parts of the Outer Hebrides.
    - By 2050 – 2079 for August there is a large increase in this upland area shifting from surplus water to a deficit.
    - Large parts of eastern Scotland in September are projected to see a shift to CWB deficit.

- For both the 2020 – 2049 and 2050 – 2079 periods there is good agreement between the 12 projections that October through to March will remain in CWB surplus (precipitation is greater than evapotranspiration.

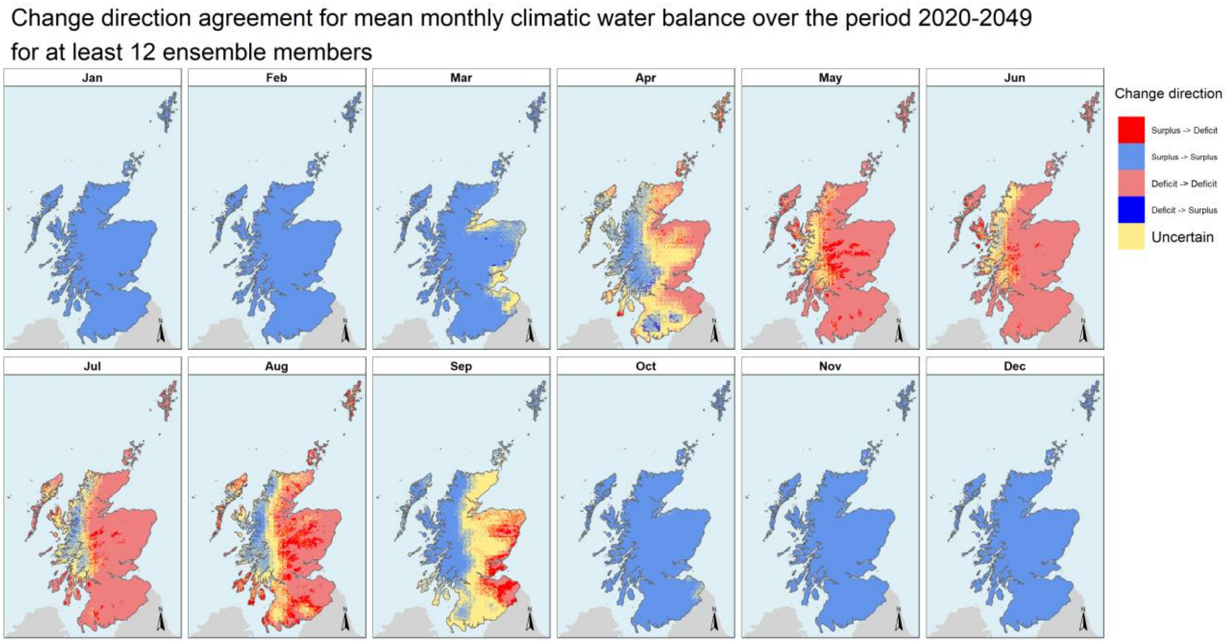

Figure 1. Agreement maps for the change direction (increase: blue/ decrease: red) of the Climatic Water Balance for the period 2020 – 2049 for all 12 climate projections (ensemble members) relative to the baseline period 1960-1989. Yellow areas indicate no agreement between projections (Rivington and Jabloun, 2022)

Habitat type map

Natural Capital (NC) assets were mapped using the UKCEH Land Cover Map (LCM) for 2020. UK CEH LCMs map land cover by describing the physical material on the surface of the UK providing an uninterrupted national dataset of land cover classes. Land cover in the newer products (post 2015) is given as 21 UKCEH Land Cover Classes based upon UK BAP Broad Habitats[1] (Figure 2 and Table 1). Recent UKCEH LCMs (post 2015) have been created using new automatic techniques that combine Bootstrap Training with a Random Forest (RF) classifier to classify Sentinel-2 Seasonal Composite Images generated using the Google Earth Engine, representing median reflectance per season (Morton et al., 2021).

For the purposes of this work, we selected the main six (6) terrestrial LCM habitat types: Arable land, Broadleaf woodlands, Coniferous Woodlands, Improved grasslands, Mountain, Heath, and Bog habitats, and Seminatural grasslands, the last two types being aggregated cover classes (Table 1). Around 99% of the area covered by seminatural grasslands comprise of Acid grasslands. The aggregated cover class of Mountain, Heath and Bog comprises of heather moorlands (Heather and Heather grassland), peatlands (Bogs) and mountainous scrub vegetation (Inland rock). These seminatural habitats that usually occur on peaty soils were aggregated because they show a cluster of interclass confusion due to similar spectral signatures (Morton et al., 2021). Moreover, we previously found substantial disagreement in the mapping of moorlands and peatlands when

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[1] UK BAP Priority Habitats | JNCC - Adviser to Government on Nature Conservation

comparing LCM and EUNIS land cover data layers (Gagkas et al., 2023). However, due to the policy relevance of peatlands, we also present results of exposure to climatic surplus or stress for Bogs separately.

Figure 2 gives the spatial distribution of LCM 2020 Broad Habitats at 10m grid cell, and the respective map of the Aggregated Cover classes. Figure 3 gives the spatial distribution of the selected Aggregated Cover Classes in relation to defined regions of North, East, Central, South and West of Scotland. These maps provide an insight on the spatial patterns of habitat occurrence; for example, Arable land is located mostly in the East while most of Seminatural grasslands are found in the West and are being used in relation to the respective spatial patterns of CWB change identified by Rivington and Jabloun (2022) and shown in Figure 1.

Table 1. LCM Broad Habitats and respective Aggregated cover classes along with individual national coverage.

Broad Habitat	Cover (%)	Aggregated Cover class	Cover (%)
Broadleaf woodland	7.2	Broadleaf woodland	7.2
Coniferous woodland	10.9	Coniferous woodland	10.9
Arable	7.2	Arable	7.2
Improved grassland	17.0	Improved grassland	17.0
Neutral grassland	0.0	Seminatural grassland	15.5
Calcareous grassland	0.0		
Acid grassland	15.4		
Fen	0.0		
Heather	10.0	Mountain, heath, bog	34.8
Heather grassland	13.5		
Bog	8.4		
Inland rock	2.9		
Saltwater	0.2	Saltwater	0.2
Freshwater	1.8	Freshwater	1.8
Supralittoral rock	0.5	Coastal	2.6
Supralittoral sediment	0.5		
Littoral rock	0.6		
Littoral sediment	0.7		
Saltmarsh	0.3		
Urban	0.6	Built up areas	2.9
Suburban	2.3		

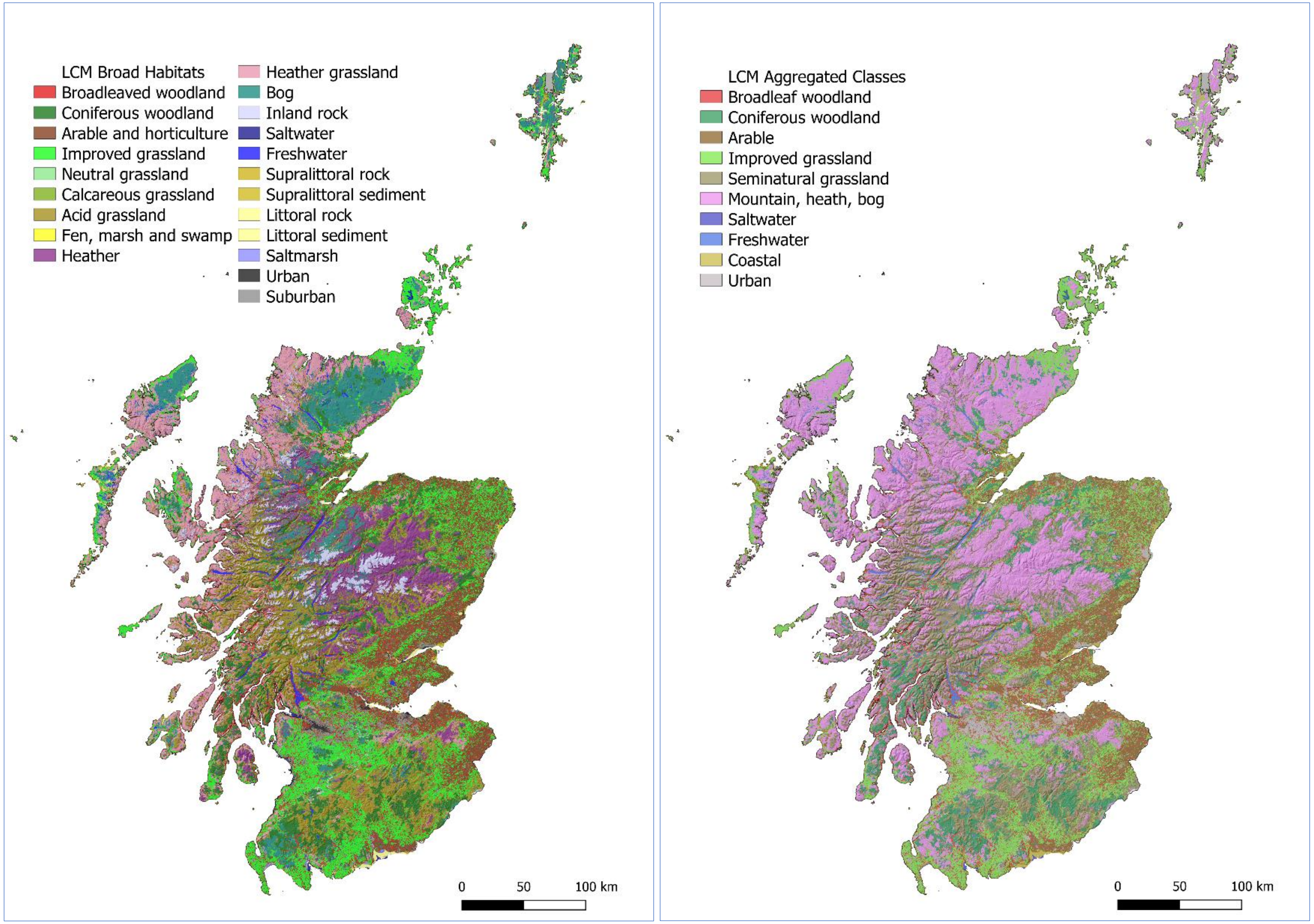
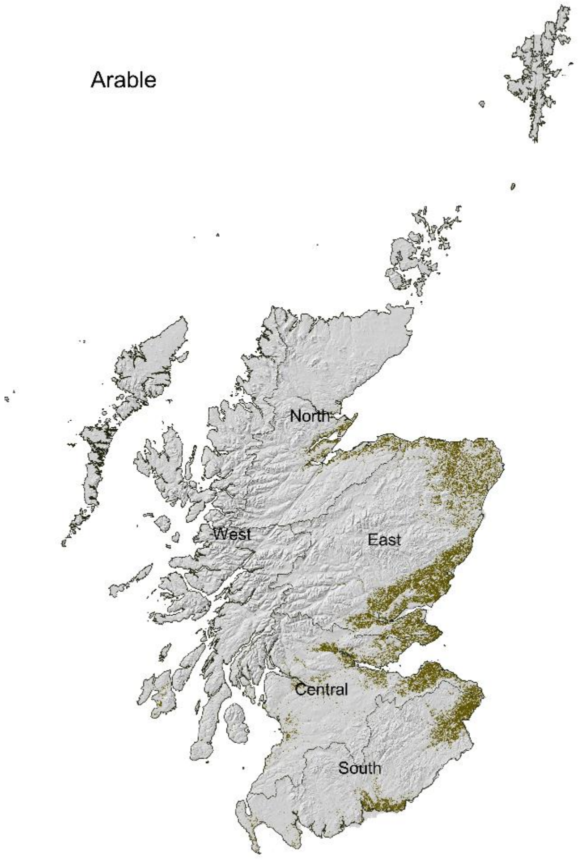
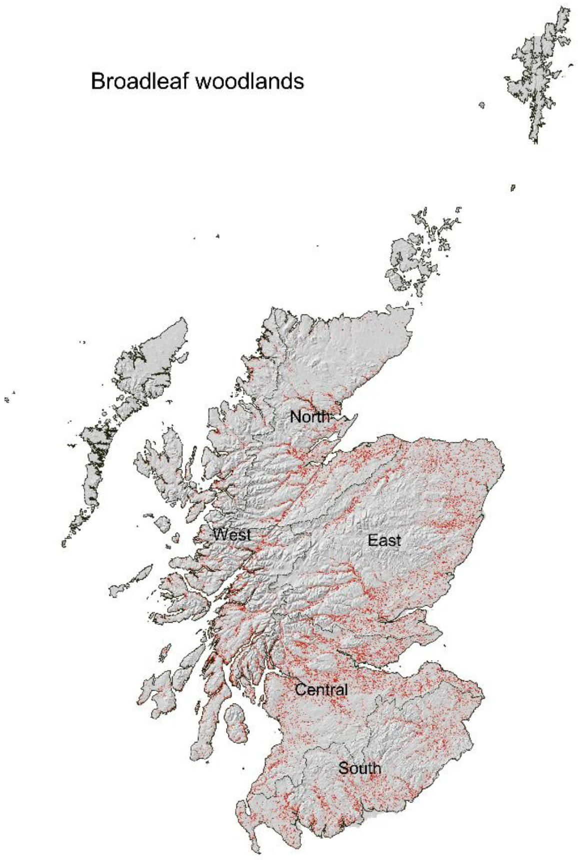
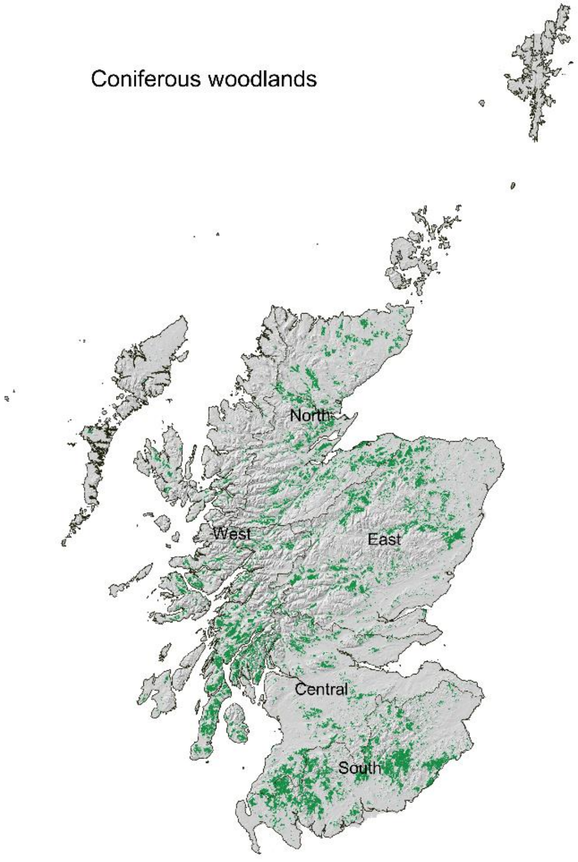
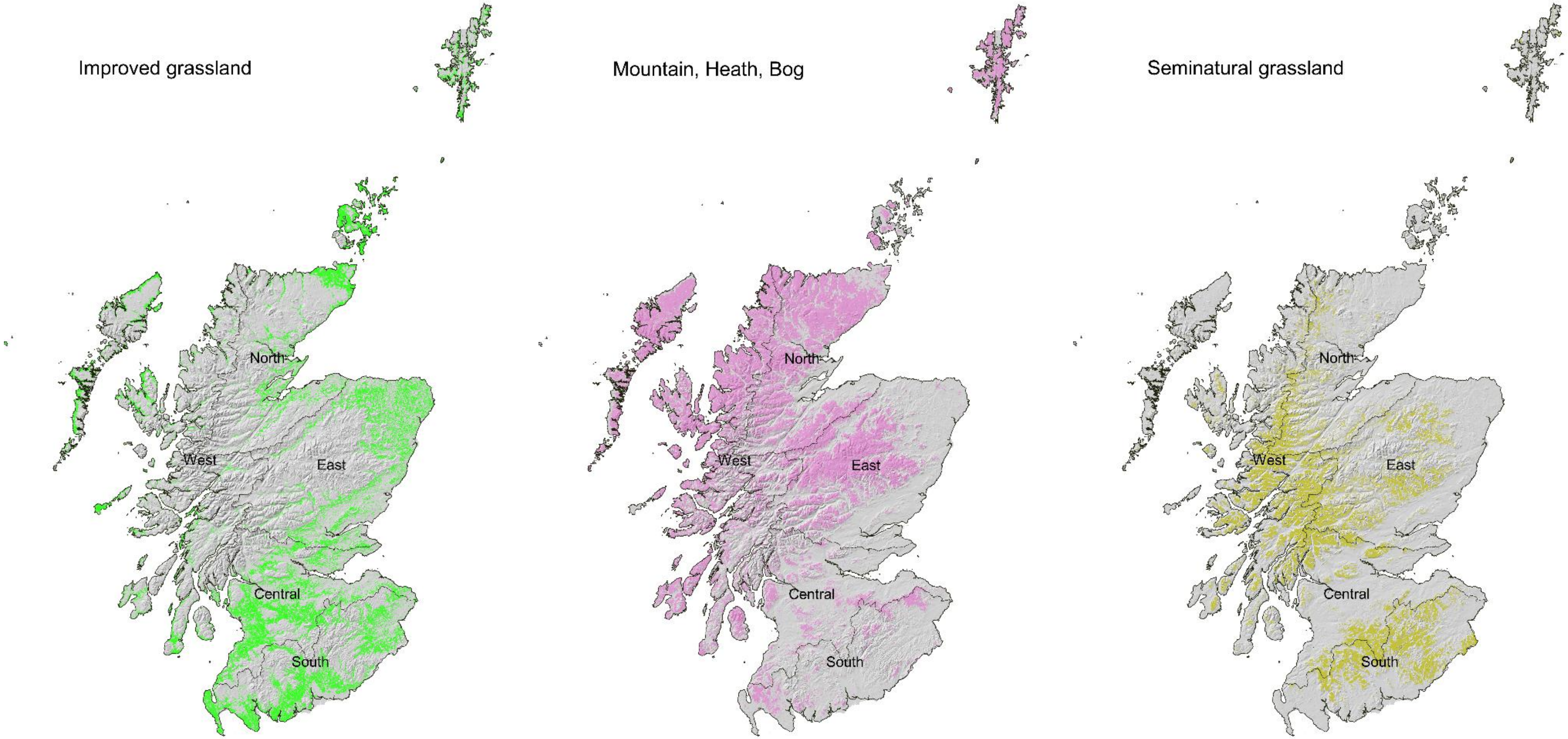


Figure 2. Land Cover Map (LCM) 2020 Broad Habitats and respective Aggregated Cover Classes.


Arable
North
West
East
Central
South


Broadleaf woodlands
North
West
East
Central
South


Coniferous woodlands
North
West
East
Central
South


Improved grassland

Mountain, Heath, Bog

Seminatural grassland

Figure 3. Spatial distribution in relation to regions of North, East, Central, South and West of Scotland of the selected Aggregated Cover Classes: Arable; Broadleaf woodland; Coniferous woodland; Improved grassland; Mountain, Heath, Bog; and Seminatural grassland. Regions were delineated based on amalgamation of main river basins.

Climate Water Balance direction of change

LCM Aggregated Cover

Here we present plots showing the proportions of the areal extent of the selected Aggregated Cover classes in relation to monthly Climate Water Balance (CWB) direction of change classes relative to the baseline period (1960-1989) (Figures 5 – 9). This indicates whether the CWB shifts from surplus to a deficit (meaning shifting from an excess of water to a shortage), remains at a surplus or deficit or shifts from a deficit to a surplus. These are presented for the observed period (1990 – 2019) and for the future periods (2020 – 2049 and 2050 – 2079). For easier visualisation and interpretation, instead of presenting plots for all climate projections (referred to as Ensemble Members, EM), we selected and presented results for those two that represent the most extreme projections: EM04 (wettest and least dry scenario for 2020-2049 and 2050-2079, respectively) and EM13 (driest scenario for both future periods) (Figure 4)[2]. Monthly summary statistics of habitat area proportions along with respective plots for all 12 EMs for both future periods are given in Tables A1 – A6 and Figures A1 – A25, respectively, in the Appendix.

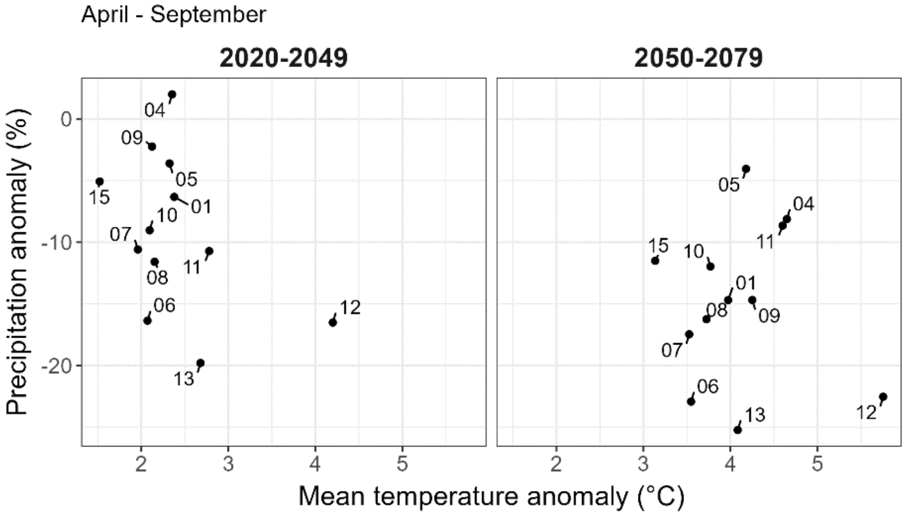


Figure 4. Climate Anomaly: ensemble member anomaly as compared to the baseline period.

Plots shown below give the national area proportions for the monthly change direction in CWB for the selected Aggregated Cover Classes for the observed period of 1990-2019 (Figure 5), the future period of 2020 – 2049 using climate projections from EM04 (wettest, Figure 6) and EM13 (driest, Figure 7) and the future period of 2050 – 2079 using climate projections from EM04 (Figure 8) and EM13 (Figure 9). These plots provide a visual comparison of the exposure of different habitat types based on the classes of direction of CWB change for the observed and projected future periods. Results presented in these plots are then discussed in the following sections by habitat type (Aggregated Cover class). We also present in Figure 10 the monthly change direction in CWB for the observed and projected future periods specifically for bogs/peatlands as mapped by LCM 2020.

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[2] Note: Analysis of all 12 projections is possible, to capture the range of plausible future climates and impacts on Natural Capital.

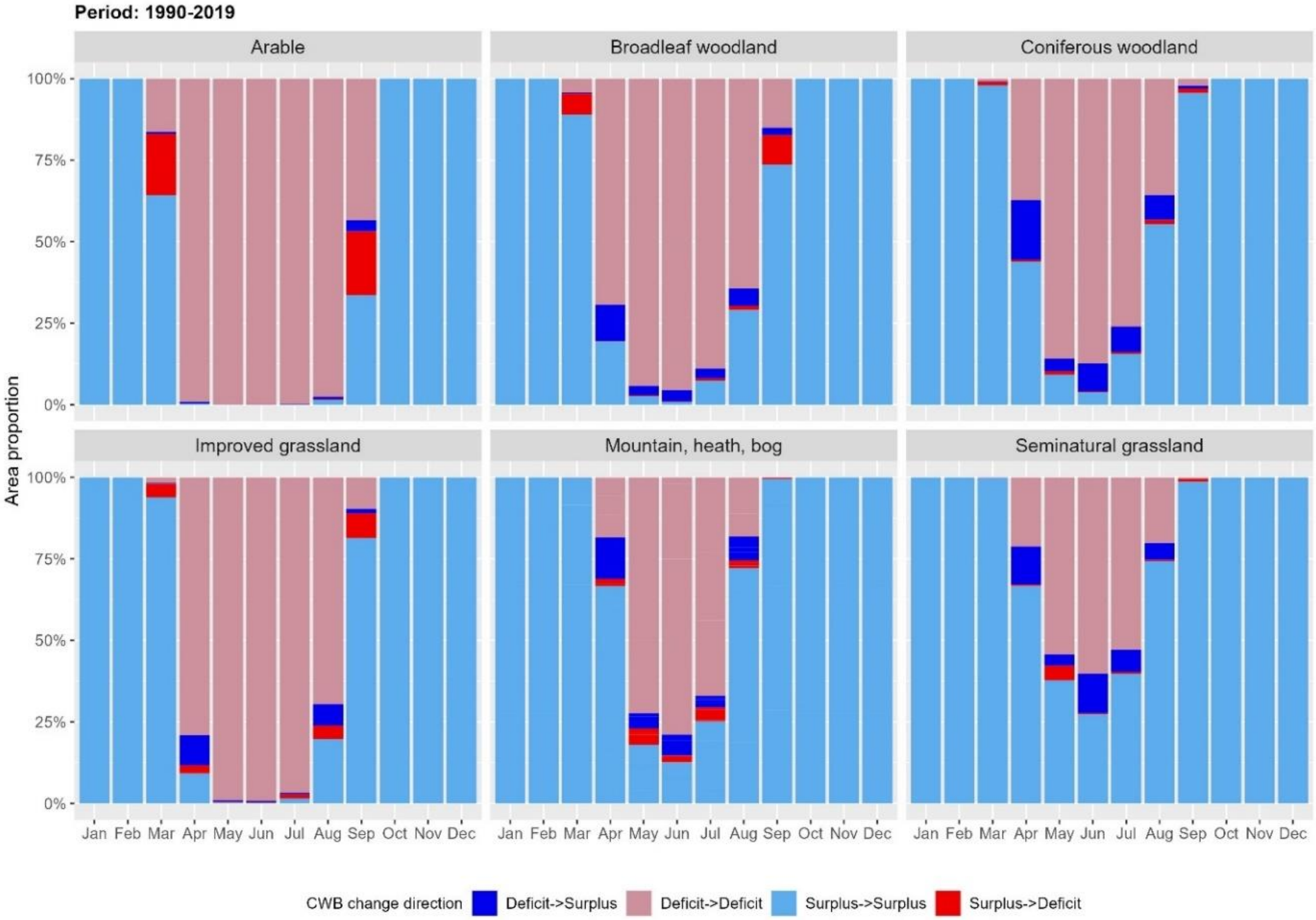


Figure 5. Area proportions for the monthly change direction in Climatic Water Balance for the selected Aggregated Cover Classes for the 1990 – 2019 period relative to the baseline period 1960-1989.

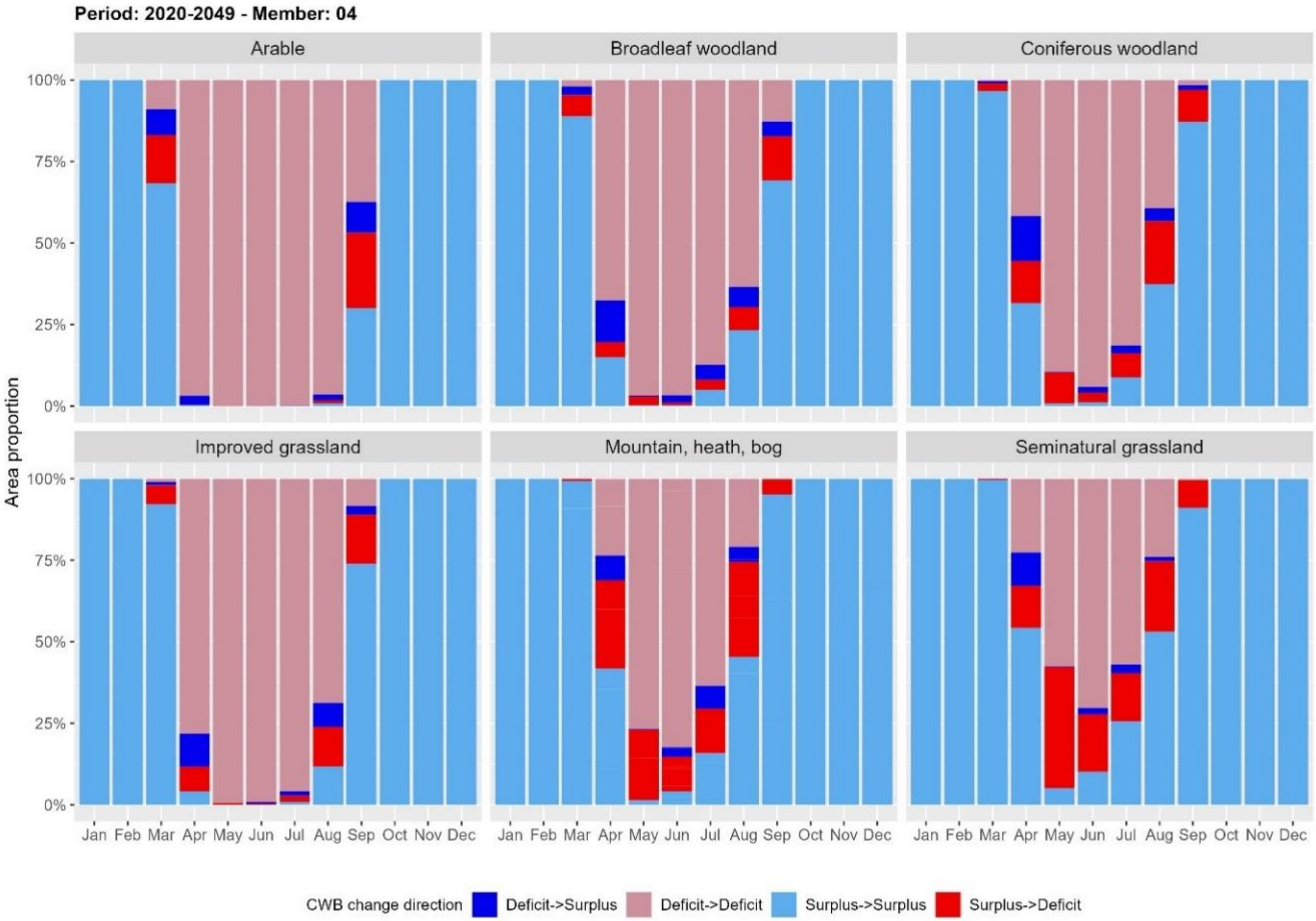


Figure 6. Area proportions for the monthly change direction in Climatic Water Balance for the selected Aggregated Cover Classes for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM04 (wettest example).

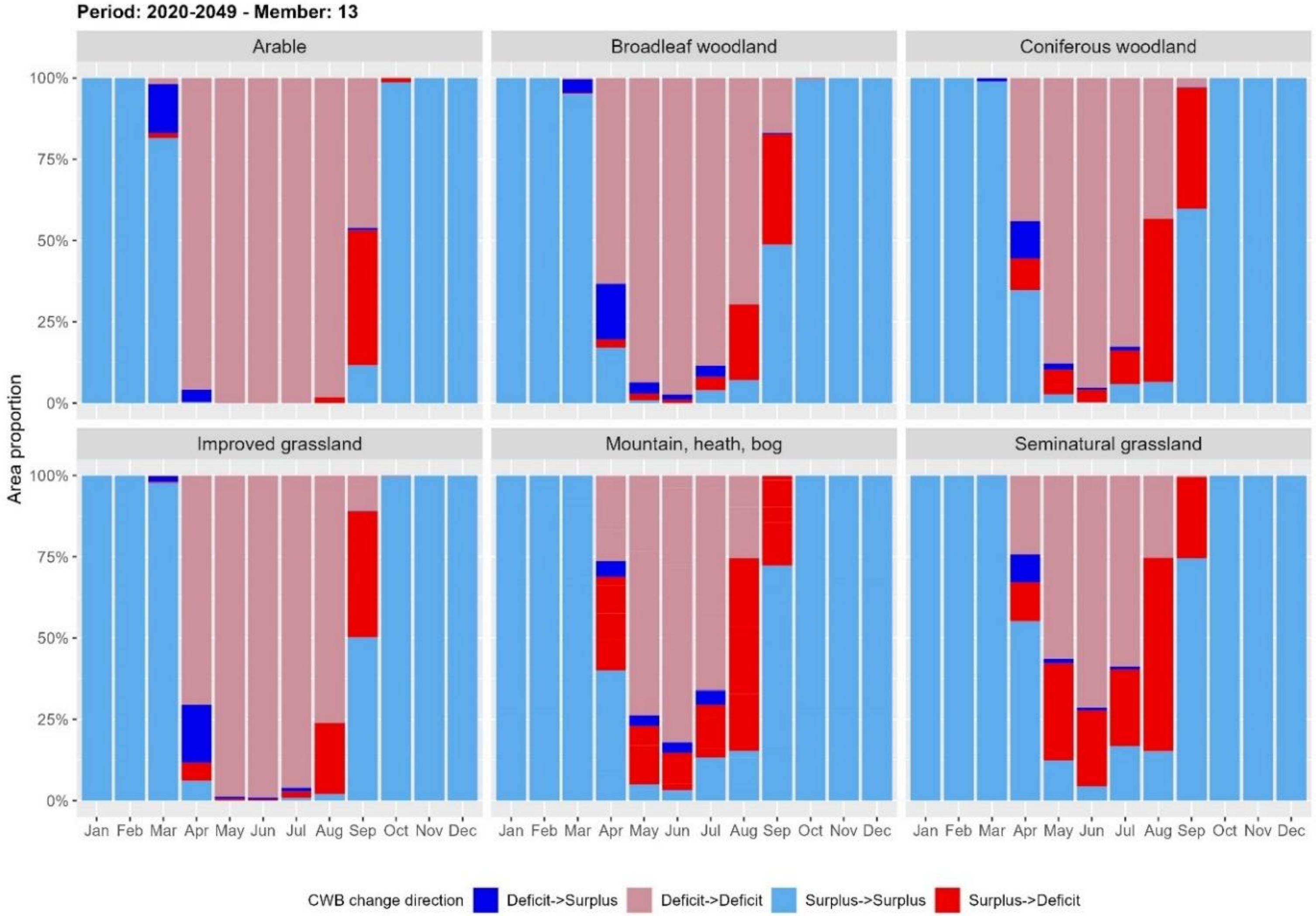


Figure 7. Area proportions for the monthly change direction in Climatic Water Balance for the selected Aggregated Cover Classes for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM13 (driest example).

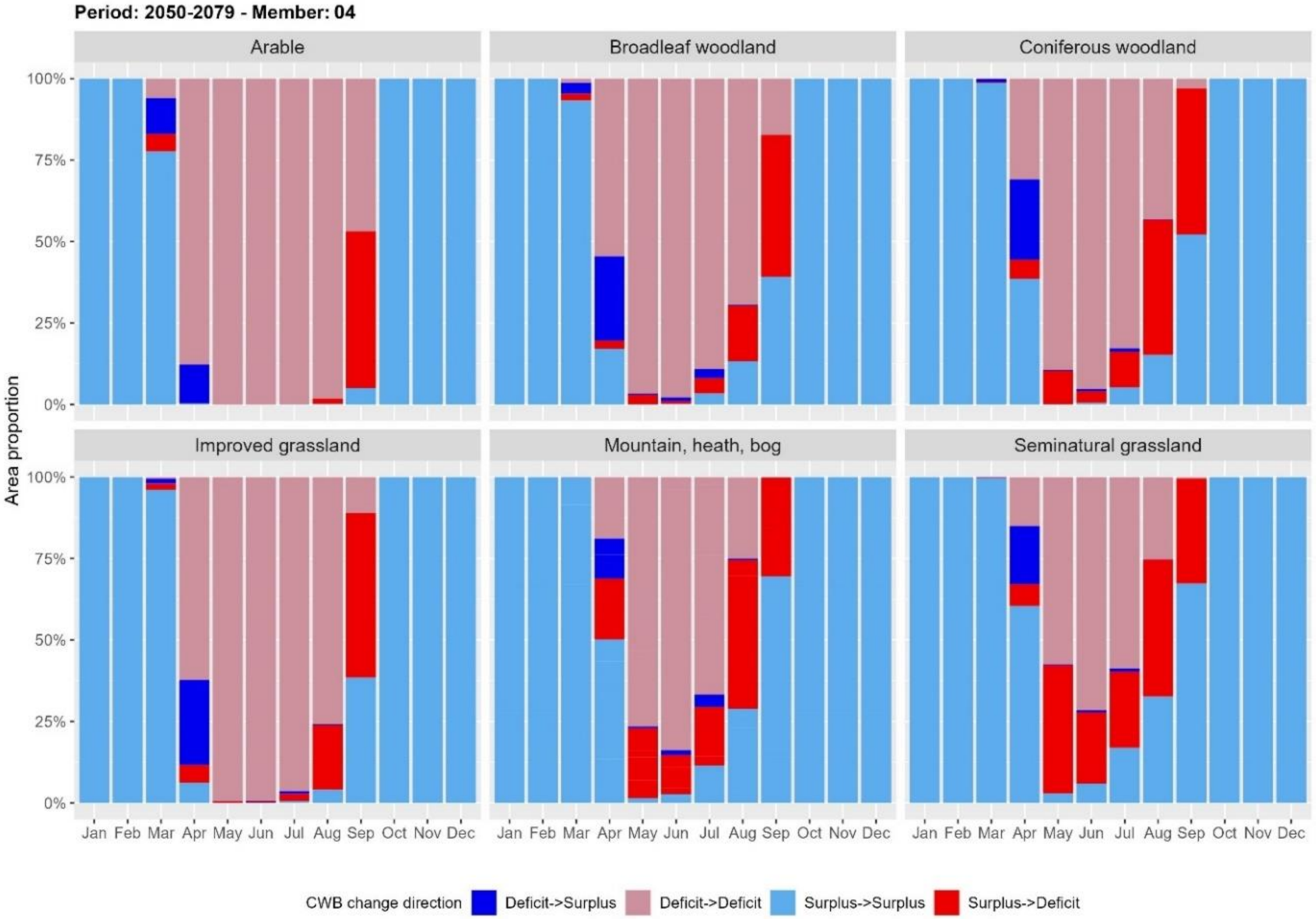


Figure 8. Area proportions for the monthly change direction in Climatic Water Balance for selected Aggregated Cover Classes for the period 2050 – 2079 relative to the baseline period 1960-1989 using climate projections from EM04 (wettest example).

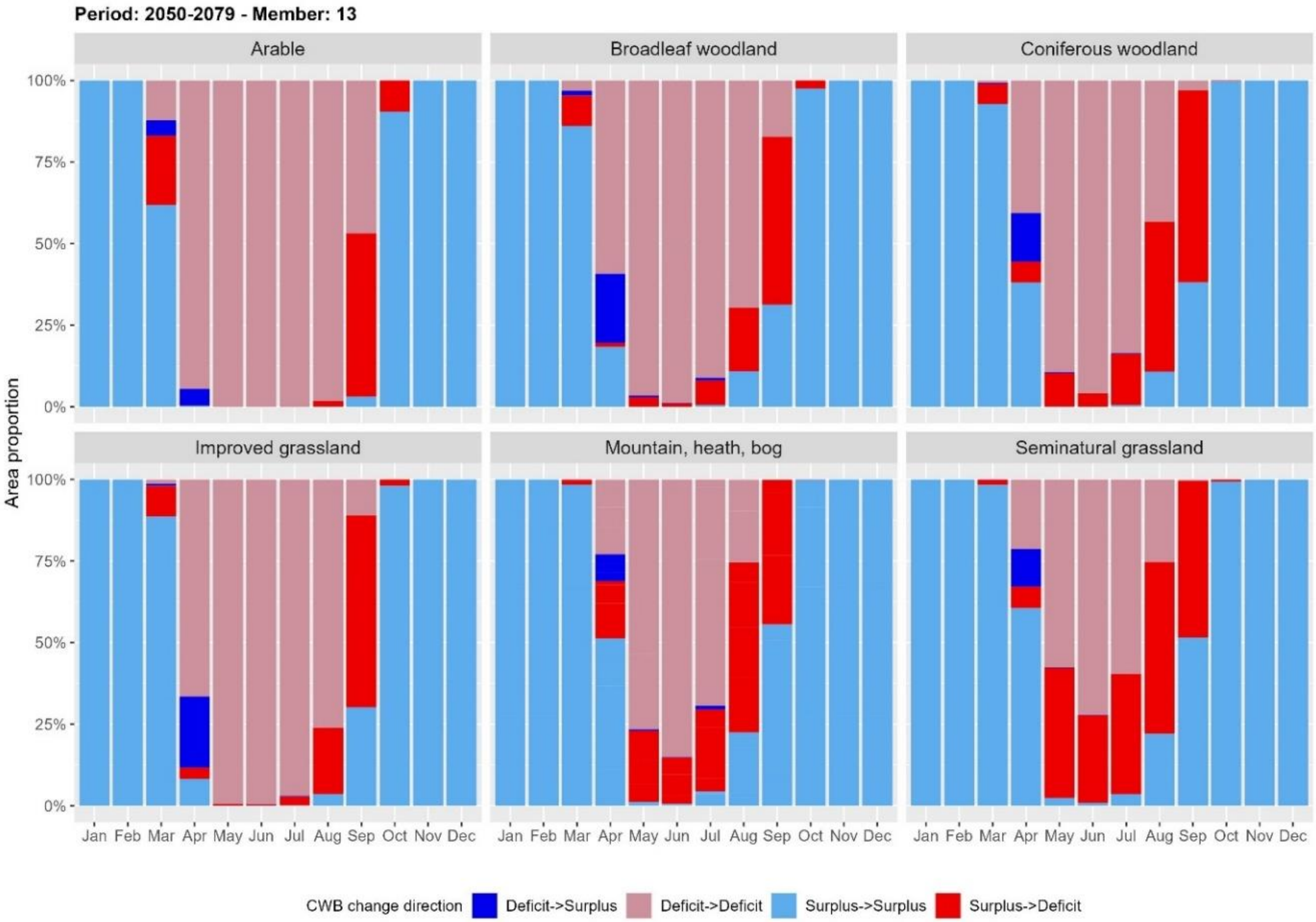


Figure 9. Area proportions for the monthly change direction in Climatic Water Balance for the selected Aggregated Cover Classes for the period 2050 – 2079 relative to the baseline period 1960-1989 using climate projections from EM 13 (driest example).

Arable land

- Observed period 1990 – 2019: Almost all 1km grid cells with arable land were in continuous water deficit for the April to August period and in water surplus from October to February. In March, 65% of arable land was still in water surplus, while in September 64% of arable land was in water deficit before recovering from October onwards.
- Future period of 2020 – 2049:
    - EM04: Almost all 1km grid cells with arable land are in continuous water deficit for the April to August period and in water surplus from October to February. In March, 76% of arable land is still in water surplus, while in September 60% of arable land is in water deficit before recovering from October onwards.
    - EM13: Around 88% to 100% of 1km grid cells with arable land are in water deficit from mid spring to late summer (April to August) and 96% to 100% of arable land cells are in water surplus from September to March.
- Future period of 2050 – 2079:
    - EM04: Around 85% to 100% of 1km grid cells with arable land are in continuous water deficit for the April to September period and almost all arable grid cells are in water surplus from October to February. In March, 89% of arable land is also in water surplus.
    - EM13: Around 90% to 100% of 1km grid cells with arable land are in water surplus from October to February, while 67% of the arable grid cells are also in surplus in March. On the other hand, around 95% to 100% of arable grid cells are in deficit for the April to September period.

Broadleaf woodland

- Observed period 1990 – 2019: Around 75% to 100% of 1km grid cells containing broadleaf woodlands were in water surplus from September to March, around 64% of broadleaf woodland area went into water deficit in April, and then around 95% of the area stayed in deficit between May and July. Recovery started in August when water deficit dropped to 65% of the broadleaf woodland grid cells.
- Future period 2020 – 2049:
    - EM04: Around 75% to 100% of 1km grid cells containing broadleaf woodlands are in water surplus from September to March, around 72% of broadleaf woodland area goes into water deficit in April, and then 90%-100% of the area stays in water deficit between May and July. Recovery starts in August when water deficit drops to 70% of the broadleaf woodland grid cells.
    - EM13: Around 95% to 100% of 1km grid cells containing broadleaf woodlands are in water surplus from October to March, around 66% of broadleaf woodland area goes into water deficit in April, and then 92%-100% of the area stays in water deficit between May and August. Recovery starts in September when broadleaf woodland grid cells under water deficit drop to 51%.
- Future period 2050 – 2079:
    - EM04: Around 93% to 100% of 1km grid cells containing broadleaf woodlands are in water surplus from October to March, around 60% of broadleaf woodland area goes into water deficit in April, and then almost of the area stays in water deficit between May and July,

    dropping to 86% in August. Recovery starts in September when 39% of the broadleaf woodland grid cells shift to water surplus, but still, most of this area is under deficit.
  - EM13: Around 90% to 100% of 1km grid cells containing broadleaf woodlands are in water surplus from October to March, around 60% of broadleaf woodland area goes into water deficit in April, and then around 90% to 100% of the area stays in water deficit between May and August. Recovery starts in September when 31% of the broadleaf woodland grid cells shift to water surplus, but most of this area is under water deficit.

Coniferous woodland

- Observed period 1990 – 2019: Almost all of 1km grid cells containing coniferous woodlands were in water surplus from September to March, while around 62% of these cells were still in water surplus in April. Water deficits were observed in 86%, 87% and 77% of coniferous woodland grid cells in May, June, and July, respectively, while 63% of the coniferous woodlands area returned to water surpluses in August.
- Future period 2020 – 2049:
  - EM04: Around 88% in September and then almost all of 1km grid cells containing coniferous woodlands from October to March are in water surplus. Around 55% of the coniferous woodland grid cells shifts to water deficit in April, while water deficits are observed in 90%-100% of coniferous woodland grid cells in May, June, and July, and in around 60% in August.
  - EM13: Around 60% in September and then almost all of 1km grid cells containing coniferous woodlands from October to March are in water surplus. Around 54% of the coniferous woodland grid cells shift to water deficit in April, while water deficits are observed in 90%-100% of coniferous woodland grid cells in the May to August period, while 60% of the coniferous woodland grid cells shift to water surplus in September.
- Future period 2050 – 2079:
  - EM04: Almost all of 1km grid cells containing coniferous woodlands from October to March are in water surplus. Around 38% of the coniferous woodland grid cells shift to water deficit in April, while water deficits are observed in 85%-100% of coniferous woodland grid cells in May, June, July, and August, dropping to 48% in September when most of the coniferous woodland grid cells are in water surplus.
  - EM13: Around 90% to 100% of 1km grid cells containing coniferous woodlands from October to March are in water surplus. Around 47% of the coniferous woodland grid cells shift to water deficit in April, while water deficits are observed in 90%-100% of coniferous woodland grid cells in the May to August period, dropping to 62% in September when most of the coniferous woodland grid cells are still in water deficit.

Improved grassland

- Observed period 1990 – 2019: Around 80% to 100% of 1km grid cells containing improved grasslands were in water surplus from September to March, around 80% of improved grasslands went into water deficit in April, and then almost 100% of the area stayed in deficit between May and July. Recovery started in August when water deficit dropped to 72% of the coniferous woodland grid cells.

- Future period 2020 – 2049:
    - EM04: Around 77% to 99% of 1km grid cells containing improved grasslands are in water surplus from September to March, around 85% of improved grasslands goes into water deficit in April, and then almost 100% of the area stays in deficit between May and July, and 80% of cells stay in water deficit in August.
    - EM13: Almost all of 1km grid cells containing improved grasslands are in water surplus from October to March, around 77% of improved grasslands go into water deficit in April, and then almost 100% of the area stays in deficit between May and August, and 50% of cells shift to water surplus in September.
- Future period 2050 – 2079:
    - EM04: Almost all of 1km grid cells containing improved grasslands are in water surplus from October to March, around 70% of improved grasslands goes into water deficit in April, and then almost 100% of the area stays in deficit between May and August, and 60% of cells stay still in water deficit in September.
    - EM13: Around 90% to 100% grid cells containing improved grasslands are in water surplus from October to March, around 70% of improved grasslands goes into water deficit in April, and then almost 100% of the area stays in deficit between May and August, and 70% of cells stay still in water deficit in September.

Mountain, Heath, Bog

- Observed period 1990 – 2019: Around 80% to 100% of 1km grid cells containing areas of heather moorlands and peatlands were in continuous water surplus from August to April. Water deficits were observed for the period from May to July in around 70% to 80% of the heathlands and bogs grid cells.
- Future period 2020 – 2049:
    - EM04: Around 90% to 100% of 1km grid cells containing areas of heather moorlands and peatlands are in continuous water surplus from September to March. CWB is split evenly (50%-50%) between surplus and deficit in April and August for the heathland and peatland grid cells. Water deficits are observed in May and June for >90% of the heathland and peatland grid cells but grid cells in water deficit fall to 77% in July.
    - EM13: Almost all of 1km grid cells containing areas of heather moorlands and peatlands are in continuous water surplus from October to March, while 72% of these cells are also in water surplus in September. In April, 55% of heathland and peatland grid cells shift to water deficit, which persists for around 80% to 90% from May till August.
- Future period 2050 – 2079:
    - EM04: Almost all of 1km grid cells containing areas of heather moorlands and peatlands are in continuous water surplus from October to March. Around 60% of the heathland and peatland grid cells remain in water surplus in April. Water deficits are observed in May, June, and July for >85% of the heathland and peatland grid cells but grid cells in water deficit fall to 70% in August. Around 70% of these grid cells shift to water surplus in September.
    - EM13: Almost all of 1km grid cells containing areas of heather moorlands and peatlands are in continuous water surplus from October to March. Around 45% of the heathland and peatland grid cells remain in water surplus in April. Water deficits are also observed in May

and June for around 90% and in July and August for around 85% of the heathland and peatland grid cells. Around of 70% of these grid cells shift to water surplus in September.

Seminatural grassland

- Observed period 1990 – 2019: Around 80% to 100% of 1km grid cells containing areas of seminatural grasslands were in continuous water surplus from August to April. Water deficits were observed for the period from May to July in around 55% to 60% of seminatural grassland grid cells.
- Future period 2020 – 2049:
  - EM04: Around 90% to 100% of 1km grid cells containing areas of seminatural grasslands are in continuous water surplus from September to March. Most of the seminatural grasslands area is in water surplus in April and August as well (55% and 65%, respectively). Water deficits are observed for the period from May to July in around 70% to 95% of seminatural grassland grid cells.
  - EM13: Almost all of 1km grid cells containing areas of seminatural grasslands are in continuous water surplus from September to March. Most of the seminatural grasslands area is in water surplus in April and August as well (64% and 75%, respectively). Water deficits are observed for the period from May to August in around 85% to 95% of seminatural grassland grid cells.
- Future period 2050 – 2079:
  - EM04: Almost all of 1km grid cells containing areas of seminatural grasslands are in continuous water surplus from October to March. Most of the seminatural grasslands area is in water surplus in April and September as well (78% and 67%, respectively). Water deficits are observed for the period from May to August in around 67% (August) to 97% (May) of seminatural grassland grid cells.
  - EM13: Almost all of 1km grid cells containing areas of seminatural grasslands are in continuous water surplus from October to March. Most of the seminatural grasslands area is in water surplus in April and September as well (72% and 52%, respectively). Water deficits are observed for the period from May to August in around 78% (August) to 99% (June) of seminatural grassland grid cells.

Bogs/ Peatlands

As mentioned previously, due to the policy relevance of peatlands, here we present results of exposure to climatic surplus or stress for Bogs separately (at Broad habitat layer) in addition to the presentation at Aggregated Cover level (Mountain, Heath, Bogs, Table 1). Figure 10 shows the proportions for the monthly change direction in CWB specifically for LCM Bogs for the observed period of 1990 – 2019 and the future periods of 2020 – 2049 and 2050 – 2079 using climate projections from EM04 and EM13.

<u>For the observed period 1990 – 2019:</u>

- Almost all of the peatlands 1km grid cells were in water surplus for the September to March period. Around 75% and 70% of the cells containing peatlands were also in water surplus in April and August, respectively. Around 90% to 95% of peatland grid cells were in water deficit in May, June, and July.

<u>For the future period of 2020 – 2049:</u>

- EM04: Around 98% to 100% 1km grid cells are in water surplus for the September to March period. Around 63% of these cells shift to a water deficit in April, which persists for the late spring and summer months; 100%, 98% and 93% of peatland cells are in water deficit in May, June, and July, respectively, while some recovery is observed in August when 42% of peatland cells shift to a water surplus.
- EM13: Almost all of the peatlands 1km grid cells were in water surplus for the October to March period. Around 73% of peatland cells shift to a water deficit in April, and >96% of peatland cells are in water deficit from May to August. Then, around 63% of these cells containing peatlands shift to water surplus in September.

<u>For the future period of 2050 – 2079:</u>

- EM04: Almost all of the peatlands 1km grid cells are in water surplus for the October to March period. Around 53% and 65% of the cells containing peatlands are also in water surplus in April and September, respectively. Water deficits are observed for >90% of peatlands grid cells in the May to August period.
- EM13: Almost all of the peatlands 1km grid cells are in water surplus for the October to March period. Around 57% and 52% of the cells containing peatlands shift to water deficits in April and September, respectively. Water deficits are also observed for >95% of peatlands grid cells in the May to August period.

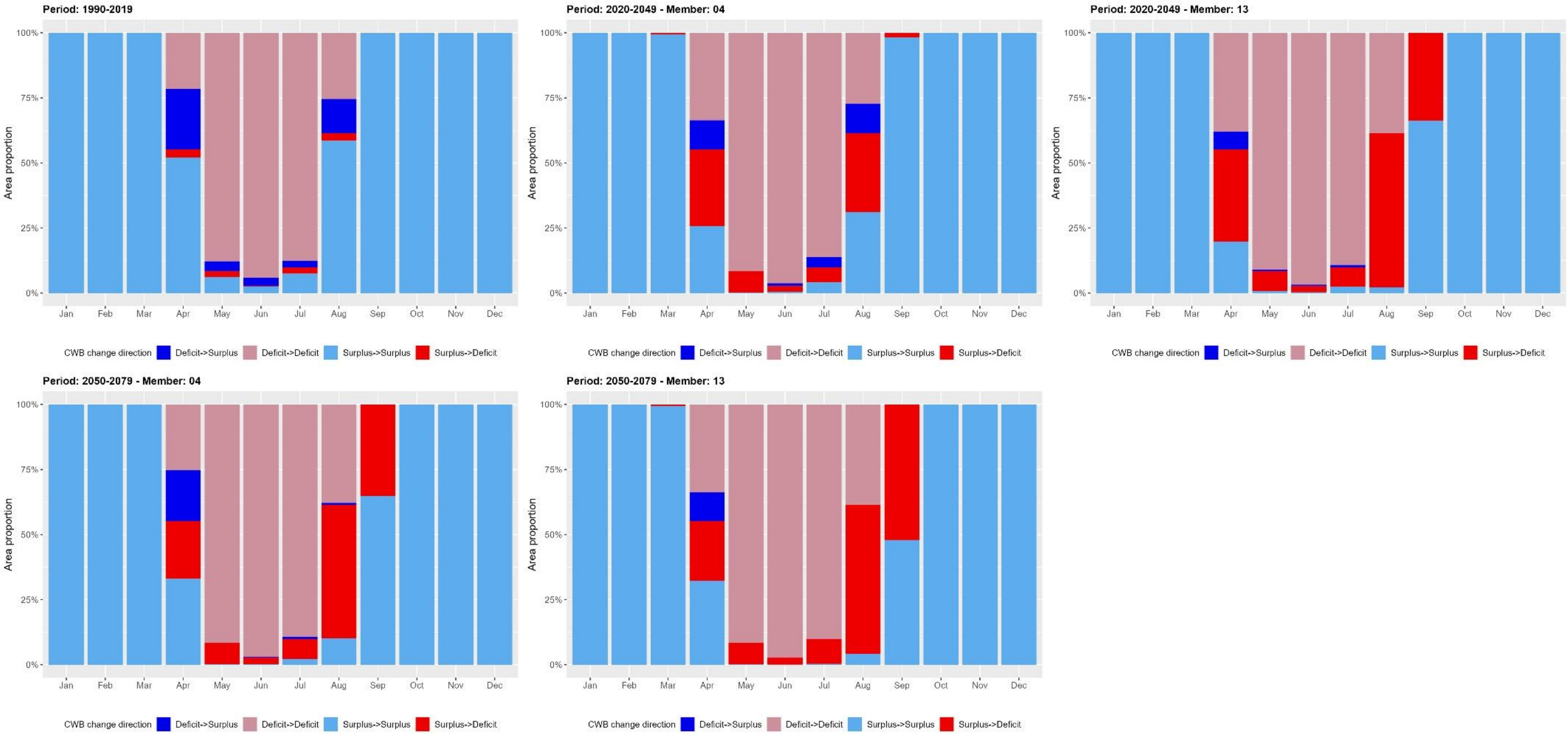


Figure 10. Area proportions for the change direction in Climatic Water Balance per month for LCM Bog for the period 1990 – 2019 and the periods 2020 – 2049 and 2050 – 2079 relative to the baseline period 1960-1989 using climate projections from Ensemble Members 04 and 13.

Discussion

Overall, most areas of all NC assets experience climatic water surplus between October to March, and climatic water deficits from May to July for the observed (1990 – 2019) and future periods (2020 – 2049 and 2050 – 2079). These deficits do not necessarily equate to actual water deficits, since CWB does not consider soil moisture and contributions from groundwater but imply a potential increased risk of water stress. Differences are mainly observed between habitats as to whether CWB swifts from surplus to deficit in April and whether water stress persists until the end of August and/or September. In this context, we can identify two main NC asset groups: Arable land, Improved grasslands, and Broadleaf woodlands, which tend to be more frequently in water deficits in April and September; and Seminatural grasslands, Mountain, Heath and Bogs and Coniferous woodlands, which tend to be less exposed to water deficits in April and September than the previous group.

For the observed period, almost all arable land is in climatic water deficit from April to August, and most of Arable land is also in deficit in September. Most of Improved grasslands and Broadleaf woodlands are also in water deficit in April, and then from May to August, but most of their area is in surplus in September. Most of Seminatural grasslands, Heathlands and Bogs and Coniferous woodlands are in water deficit from May to July, but most of the area of these habitats is in water surplus from August onwards. Seminatural grasslands are the least exposed to late spring and summer stress, followed by Heathlands and Bogs, and then Conifers.

For the future period of 2020 – 2049 and projections from EM04 (wettest scenario), the pattern of monthly CWB in Arable land, Improved grasslands, and Broadleaf woodlands is the same as in the observed period, but more of their area shifts from surplus to deficit. However, most of the area of Seminatural grasslands, Heathlands and Bogs, and Coniferous woodlands shifts from surplus to deficit in August, and in April as well for Heathlands, Bogs and Coniferous woodlands (but not for Seminatural grasslands). Looking at the EM13 projections (driest scenario), the area under water stress further increases in Arable land, Improved grasslands, and Broadleaf woodlands in April and September, while the main change for Seminatural grasslands, Heathlands and bogs, and Coniferous woodlands is that there is an increase in the area of these habitat types that are in water stress in September, but most of their area is still in water surplus.

For the future period of 2050 – 2079 and projections from EM04 (wettest scenario), most of the area of Improved grasslands and Broadleaf woodlands shifts to water stress in September, which means that most of the area Arable land, Improved grasslands and Broadleaf woodlands are in continuous water deficit from April to September (with small areas also in deficit in March). The main change for Seminatural grasslands, Heathlands and Bogs, and Coniferous woodlands is that there is a further shift to water deficits in September compared to the 2020 – 2049 period. However, most of the area of these habitats remain in surplus, while CWB in April more or less stays the same for these habitats. Looking at the EM13 projections (driest scenario), while overall CWB patterns are the same as in the 2020 – 2049 period, the area under water stress further increases in March and to a lesser extent in October for Arable land, Improved grasslands, and Broadleaf woodlands, although dominant CWB is surplus in these months for these habitats. The main change for Seminatural grasslands, Heathlands and Bogs, and Coniferous woodlands is that there is a further increase of areas in water deficit in August and September, which results in a shift from surplus to deficit for most of the area of Coniferous woodlands, but most of Seminatural grasslands and Heathlands and Bogs remain in water surplus in September.

Looking at peatlands/bogs in particular, based on the observed period of 1990 – 2019, most of peatlands are in water stress for the period from May to July, but in strong water surpluses from

August to April. The main change identified is that for both future periods (2020 – 2049 and 2050 – 2079) and Ensemble Members (EM04 and EM13) most of peatland area shifts to water stress in April and August, while their area under water deficit also increases in September, although most of it remains in surplus, with the exception of when EM013 projections are used for the 2050 – 2079 period.

Potential Increased Risks

The results of these analyses reveal high exposure levels of Arable land, and to a lesser extent of Improved grasslands, to climatic water stress, which potentially can have adverse impacts on crop yields and the provision of food and fibre for humans and livestock. Their exposure is affected by their geographical distribution, as most of Arable land and Improved grasslands are located in the Eastern side of Scotland where meteorological droughts are projected to become more frequent. In the case of Seminatural grasslands, Heathlands and Bogs, and Coniferous woodlands, the main change is related to the shift from surpluses to deficits from most of their area in the summer months and in potentially in April and September as well. This CWB shift is of concern because it may lead to an increased probability of peat becoming a source of carbon due to drying (reduction in anaerobic conditions), rather than a sink (if remaining wet and maintaining ecological functions), whilst also impacting on restoration efforts, although the impact on peatlands will also depend on broader hydrological process such as the water table height. It is also probable that fire danger for heather moorlands, peatlands, and even broadleaf and coniferous woodlands (considering ambitious plans for woodland expansion) may also increase. Wildfire incidents are most prevalent in the spring because of the availability of dead and dry fine vegetation as fuel, but widespread wildfires have also occurred in some hot, dry summers, and the expansion of the summer season towards late summer to early autumn increases the likelihood of more frequent wildfires in that period (Perry et al., 2022). This could have adverse effects on the provision of the various ecosystem services provided by these habitats (e.g., storing carbon, maintaining biodiversity, filtering waters and providing timber).

Spey case study

Overview

The purpose of this case study was to explore new metrics for quantifying the magnitude of CWB and better enabling comparisons between the baseline, observed and future projected periods, and for producing improved visualisation of these comparisons. The Spey catchment was selected because it is an extensive one with a mixture of land covers and of great importance for various land use sectors and associated industries (e.g., distilling). The Spey is also one of the catchments used by SEPA in their Drought Risk Assessment Tool (DRAT) and is included in weekly water scarcity reporting, while work in the RESAS project “D2-1: Emerging Water Futures” uses flow data series from the catchment’s outlet (Gauge ID: 8006 at Boat o’Brig) for hydrological drought modelling. Hence, work presented here can link directly with work done both by the Hutton and SEPA colleagues.

Figure 11 shows the map of LCM 2020 broad habitats for the Spey catchment, and Table 2 gives the percentages of coverage at the Aggregated Cover class level.

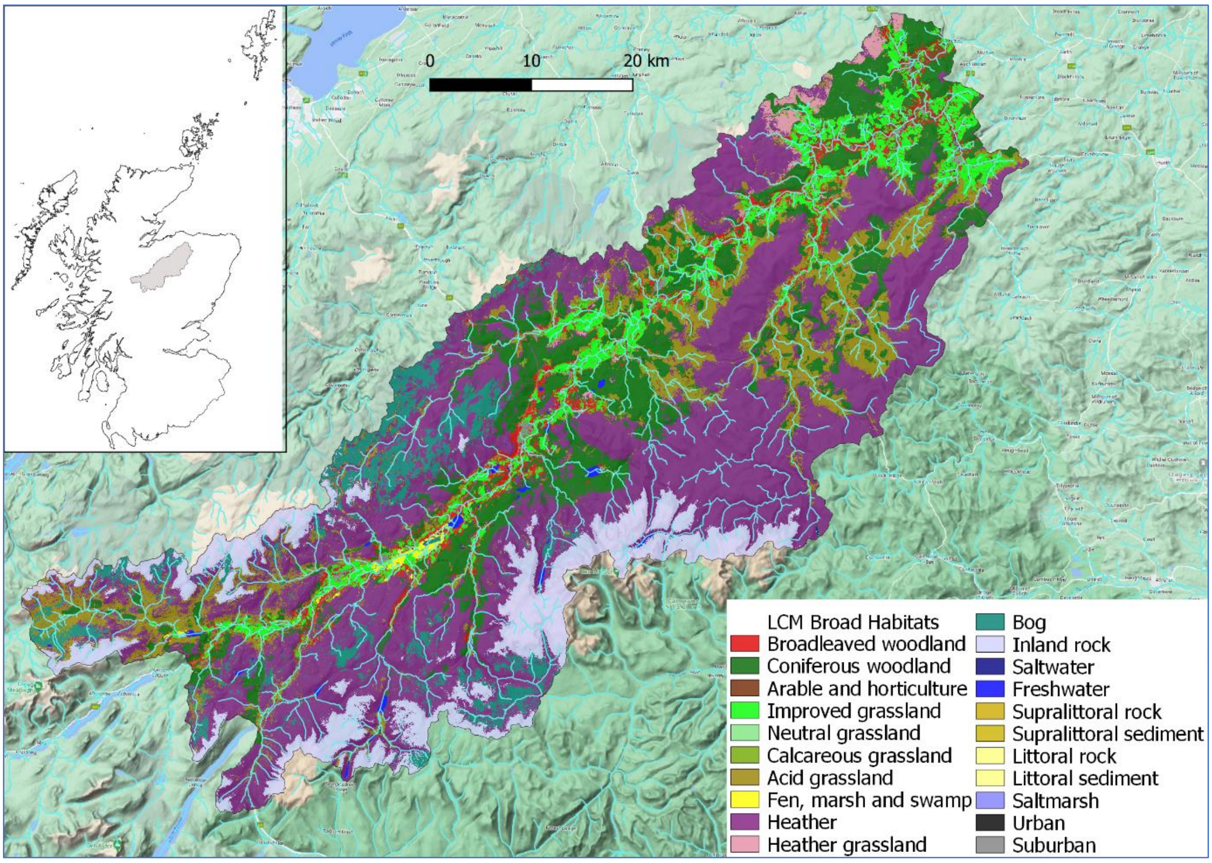


Figure 11. Map of LCM 2020 Broad Habitats in the Spey catchment. Background map provided by OpenStreetMap.

Table 2. Areas in km^2 and covers (%) of Aggregated Cover class for the Spey catchment from CEH LCM 2020.

Aggregated Cover	Area (km^2)	Cover (%)
Arable	10.0	0.3
Broadleaf woodland	123.8	4.3
Built up areas	19.3	0.7
Coastal	0.3	0.0
Coniferous woodland	440.4	15.4
Freshwater	11.6	0.4
Improved grassland	170.1	6.0
Mountain, heath, bog	1703.3	59.7
Saltwater	0.2	0.0
Seminatural grassland	373.5	13.1

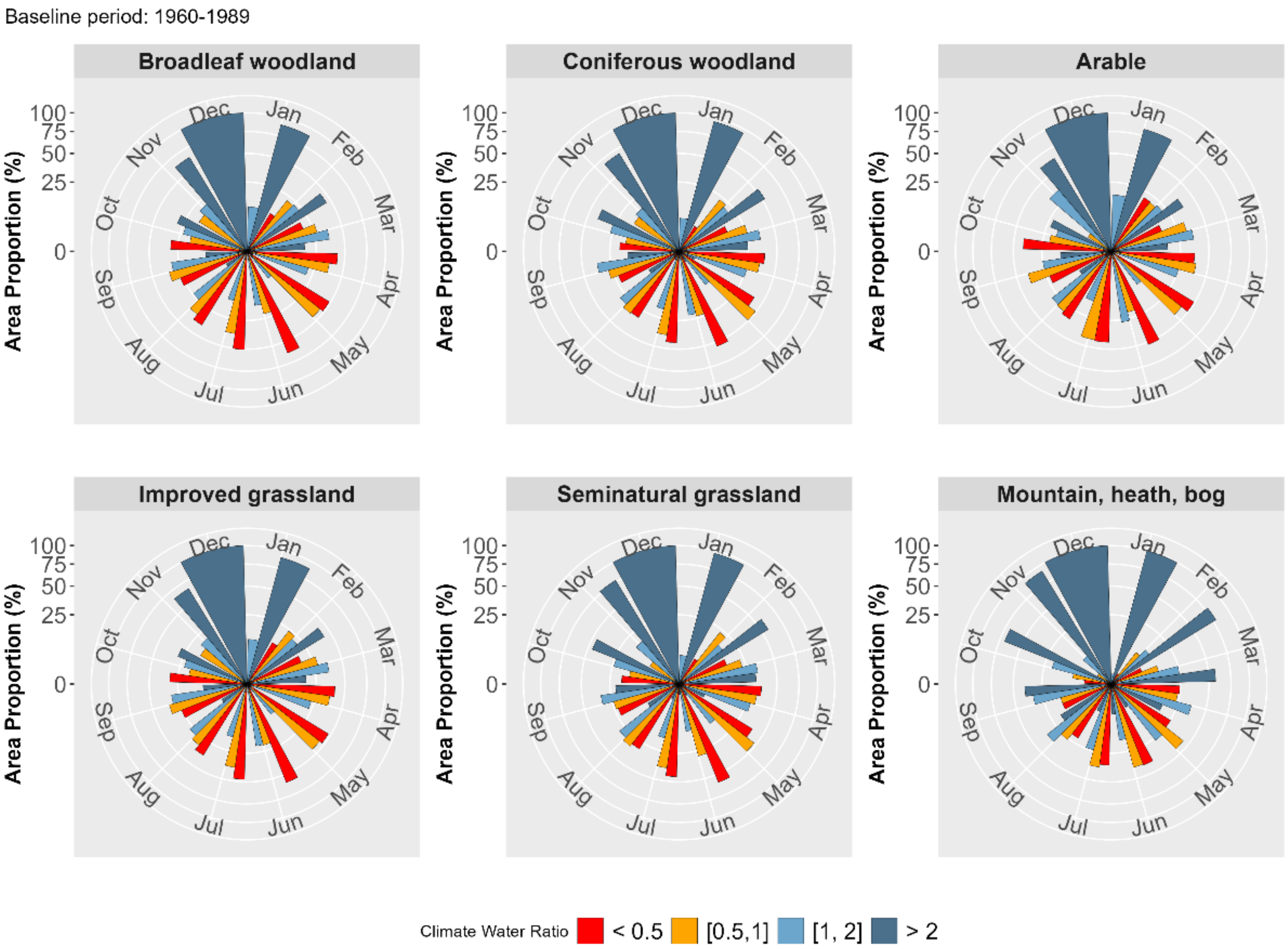
Heather moorlands, peatlands and mountainous scrub vegetation are the dominant land cover within the Spey catchment, covering almost 60% of the catchment's area, followed by Coniferous woodland (~15%) and Seminatural (Acid) grassland (~13%). Cultivated land covers only 6.3% of the catchment's area, with 6% comprising of Improved grasslands and only 0.3% being Arable land. This is because the catchment's outlet has been defined upstream of the Spey river's floodplain where most of arable land is located.

Climatic Water Balance Ratios

In this case study we are using Climatic Water Balance ratios (CWR) defined as the ratio of Precipitation (P) to Reference Evapotranspiration (ET_0) ($CWB\ ratio = \frac{P}{ET_0}$).

This approach can be used to both identify surpluses and deficits; CWR ≥ 1 denote climatic water surpluses while CWR < 1 denote climatic water deficits, but it also provides the magnitude of these surpluses or deficits; for example, CWR value above 2 indicates a strong or extreme climatic water surplus because precipitation is two times higher than evapotranspiration.

CWR were used to assess and highlight proportions of habitat type areas in climatic surplus, or in deficit as shown indicatively in Figure 11 for Aggregated Cover classes in the Spey catchment. These rose charts are circular histograms that give the proportions of habitat type areas by month for each of the following four (4) classes of CWR levels: CWR < 0.5: Severe climatic water stress, precipitation covers 50% of the evapotranspiration demand); CWR between 0.5 and 1 (moderate climatic water stress); CWR between 1 and 2 (moderate climate water surplus); and CWR > 2 ('extreme' climatic water surplus). They were calculated using mean CWR values by Aggregated Cover class using the counts of 1km grid cells covering the Spey catchment that contain at least one LCM 10m grid cell of the respective habitat type. Figure 11 provides a quick overview of the transition from high to moderate water surpluses in the winter months and the greater proportions under moderate to severe water stress during summer months for all habitat types when comparing the baseline period of 1960 – 1989 to projected future period of 2020 to 2049 based on EM04.


Baseline period: 1960-1989
Broadleaf woodland
Coniferous woodland
Arable
Improved grassland
Seminatural grassland
Mountain, heath, bog
Area Proportion (%)
100
75
50
25
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Climate Water Ratio
< 0.5
[0.5,1]
[1, 2]
> 2

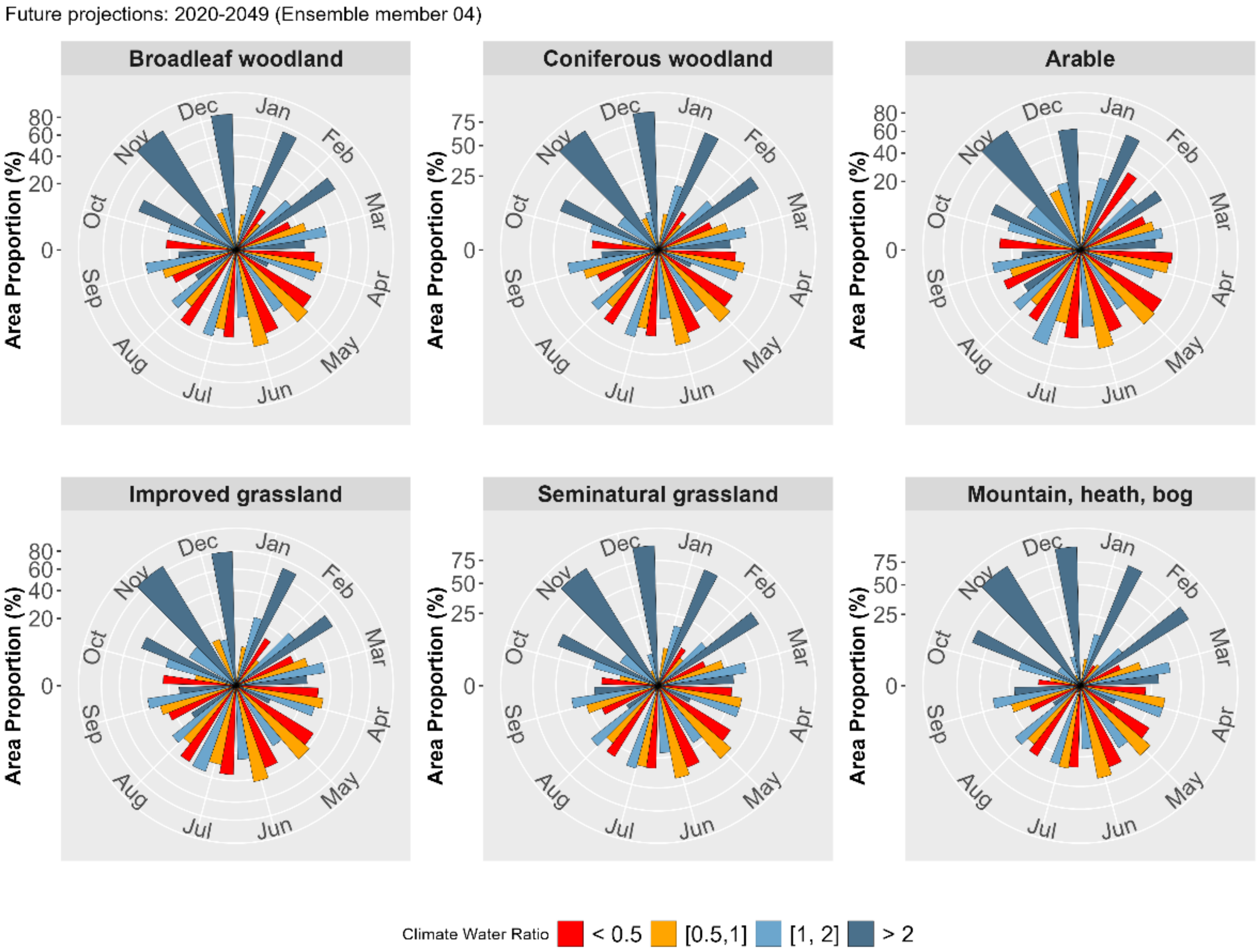


Figure 11. Monthly mean proportions of Climatic Water Balance Ratio classes by Aggregated Cover class in the Spey catchment for the for the baseline period of 1960 – 2019 (top) and the future period of 2020 - 2049 relative to the baseline period 1960-1989 using climate projections from EM04 (bottom, wettest scenario example).

A more comprehensive approach for comparing exposure levels for different habitat types between baseline to projected periods is provided by the histograms presented below, where the y-axis gives counts of 1km grid cells covering the Spey catchment that contain at least one LCM 10m grid cell of the respective habitat type and the x-axis gives the CWR values of these grid cells. The red vertical line shows when precipitation equals referenceevapotranspiration (i.e., CWR = 1 or CWB = 0), meaning that all cells to the right of this threshold are in water surplus and all cells to the left are in water deficit. Moreover, the black and blue lines provide mean or median CWR values, respectively, for all cells for each of the two time periods compared, giving an overall visual assessment of whether most of the area covered by each respective habitat type is in climatic water stress or surplus, along with the magnitude of its climatic water condition.

Below we provide indicative examples of these histograms in relation to the selected Aggregated Cover classes in the Spey catchment and by comparing CWR in the baseline period of 1960 – 1989 (cell counts in gray) with the observed period of 1990 – 2019 and future projected 2020 – 2049 using EM04 and EM13 (cell counts in blue), representing the wettest and driest projected future scenarios, respectively.

Arable land

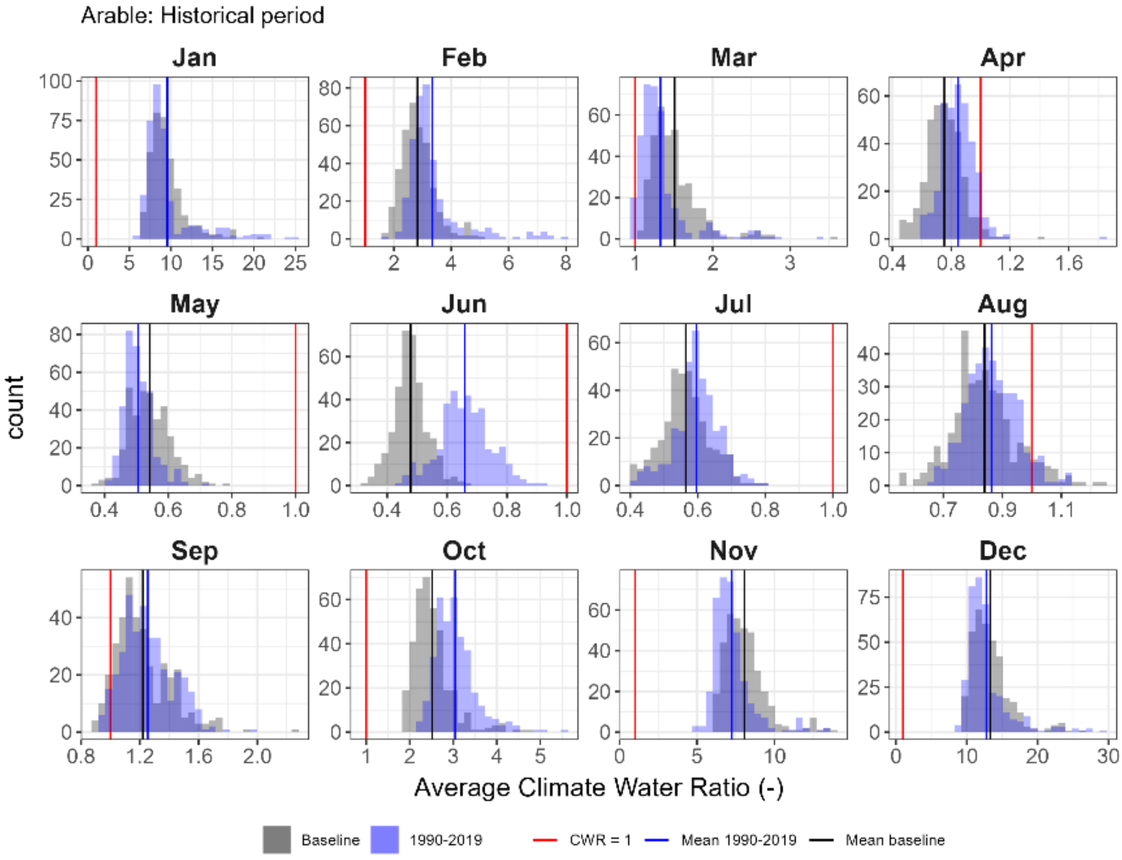


Figure 12. Spey catchment monthly Climatic Water Balance Ratios (CWR) for arable land in the 1990-2019 period.

- Similar CWR is observed for arable land in the two time periods in January: strong water surplus, July: moderate water stress, August: moderate to small water stress, September: moderate water surplus, and December: high water surplus.

- Main difference is observed in June, which shows the least overlap of the two grid cell populations, and in October when arable land in the 1990 – 2019 period is in smaller water stress and greater water surplus, respectively, than in the baseline period.

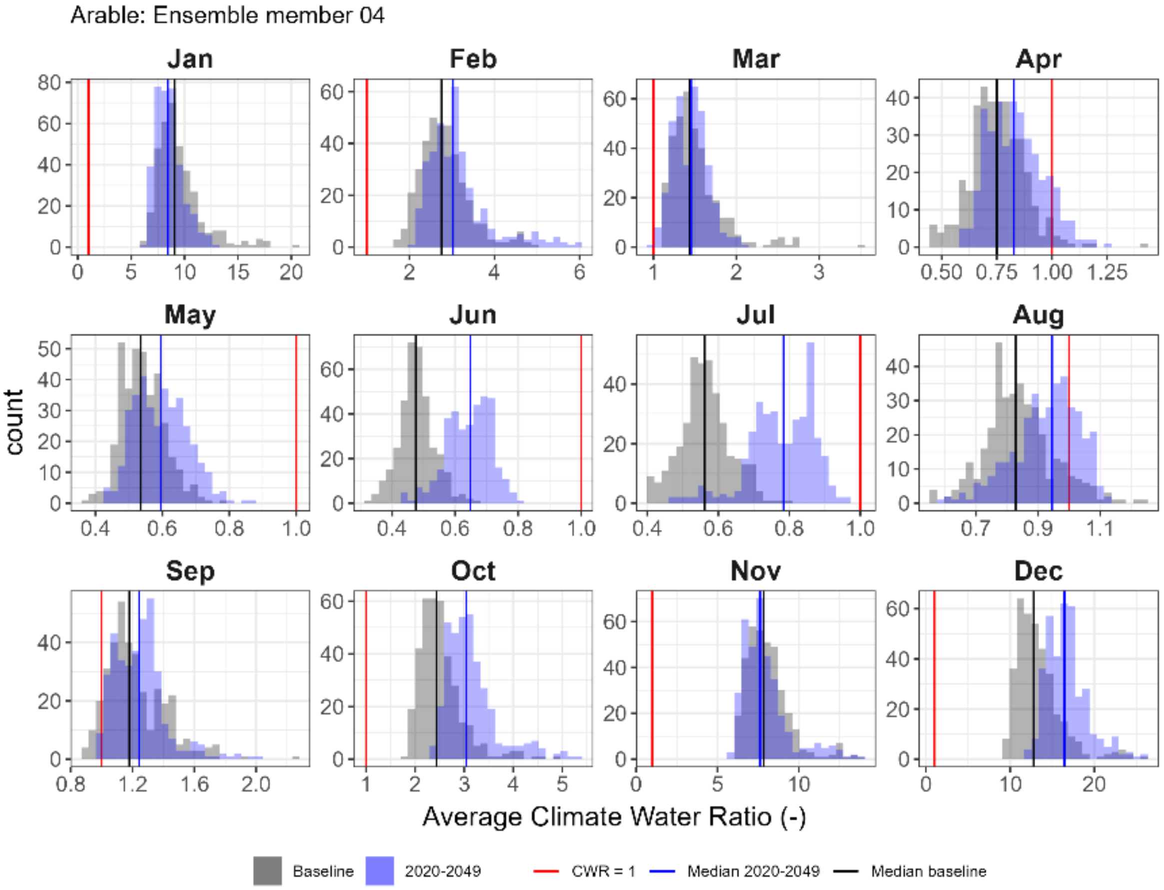


Figure 13. Spey catchment monthly Climatic Water Balance Ratios (CWR) for arable land for two future periods using Climate projection EM04 (wettest example).

- Water stress in arable land grid cells from May to August for the 2020 - 2049 period is smaller than for the baseline period.

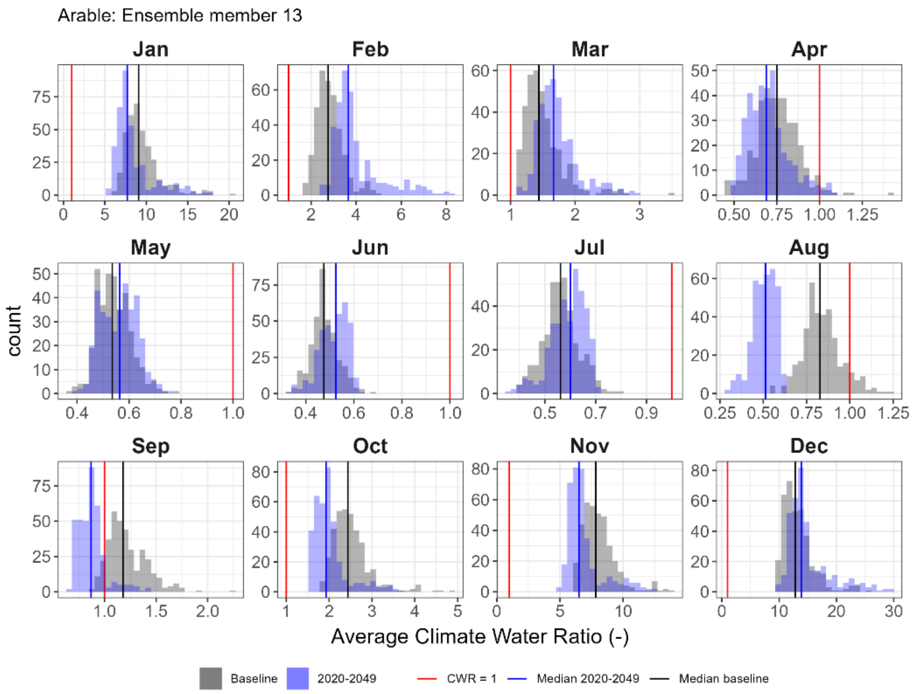


Figure 14. Spey catchment monthly Climatic Water Balance Ratios (CWR) for arable land for two future periods using Climate projection EM13 (driest example).

- Water stress in arable land grid cells from May to July for the 2020 - 2049 period is smaller than for the baseline period, but to a lesser extent than when EM04 projections are used. Conditions are generally drier for the 2020 – 2049 period, regardless of whether arable land cells are in water stress or surplus in September, October, November, January, and April.

Broadleaf woodland

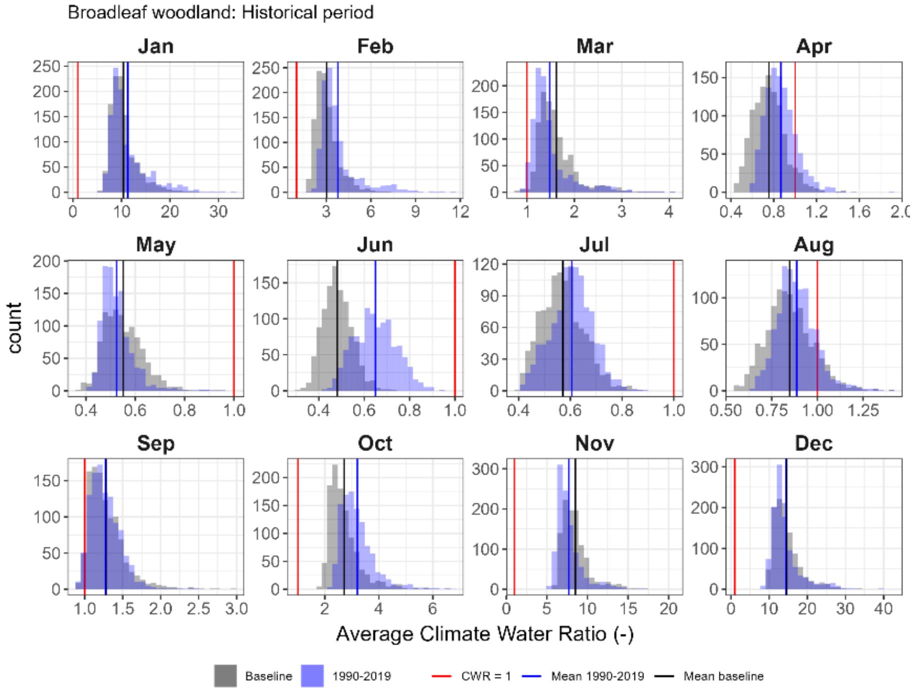


Figure 15. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Broadleaf woodland in the 1990-2019 period.

- CWR was similar in broadleaf woodland grid cells in the 1990 – 2019 period and the baseline period, with the exception of June, where smaller water stress is observed in broadleaf woodland cells for the 1990 – 2019 period compared to the baseline.

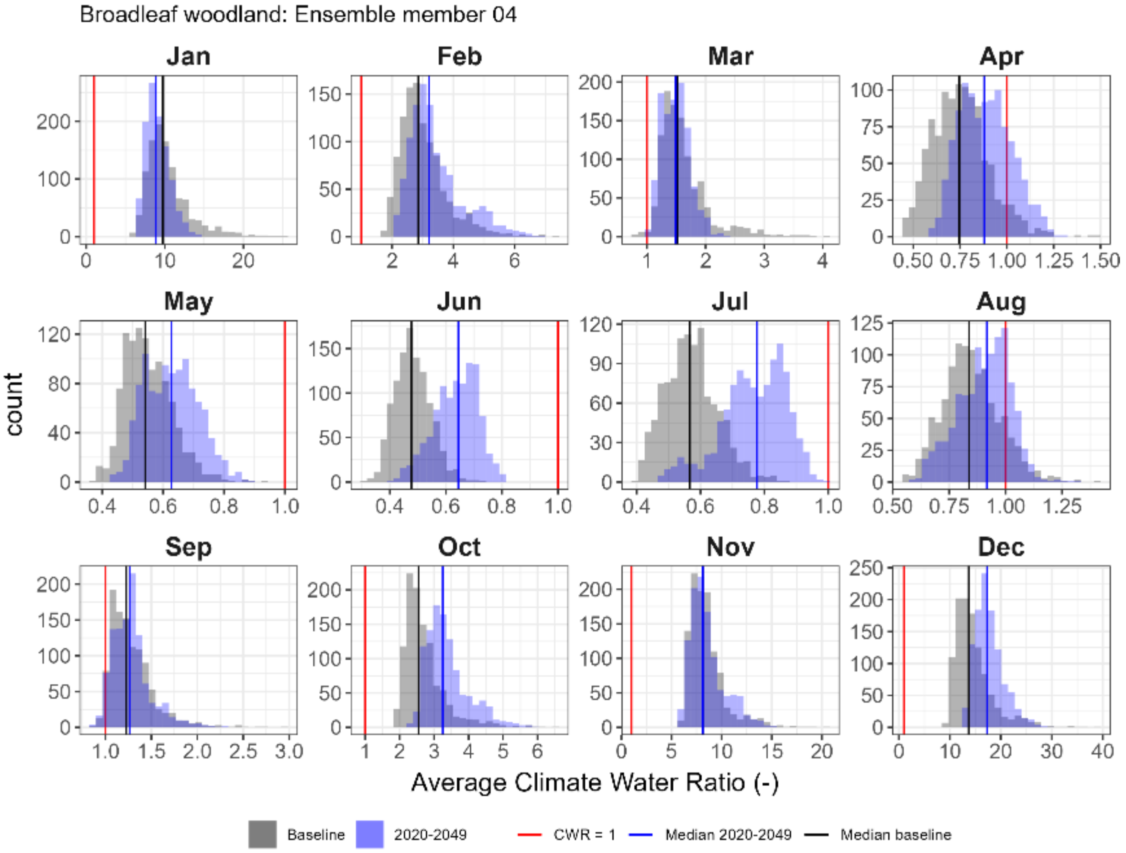


Figure 16. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Broadleaf woodland for two future periods using Climate projection EM04 (wettest example).

- CWR was similar in broadleaf woodland grid cells in the 2020 – 2049 period and the baseline period in January, February, March, September, and November. Broadleaf woodland grid cells are generally in smaller water stress from April to August for the 2020 – 2049 period compared to the baseline period.

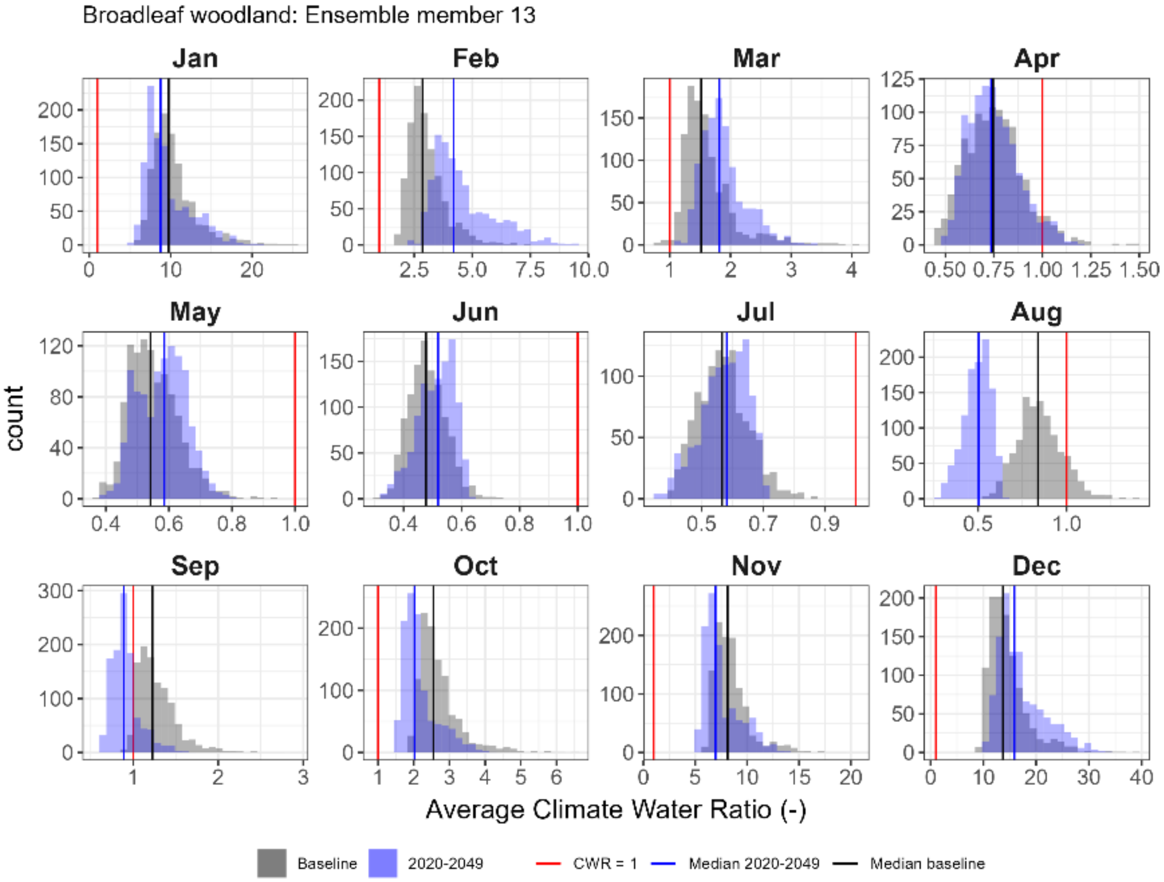


Figure 17. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Broadleaf woodland for two future periods using Climate projection EM13 (driest example).

- CWR is fairly similar in broadleaf woodland grid cells in the 2020 – 2049 period and the baseline period in January, April, May, June, July, November, and December. Broadleaf woodland grid cells are in moderate to severe stress from April to August for both time periods. Main observed difference is that broadleaf woodland grid cells are in greater water stress in August for the 2020 – 2049 period compared to the baseline period.

Coniferous woodland

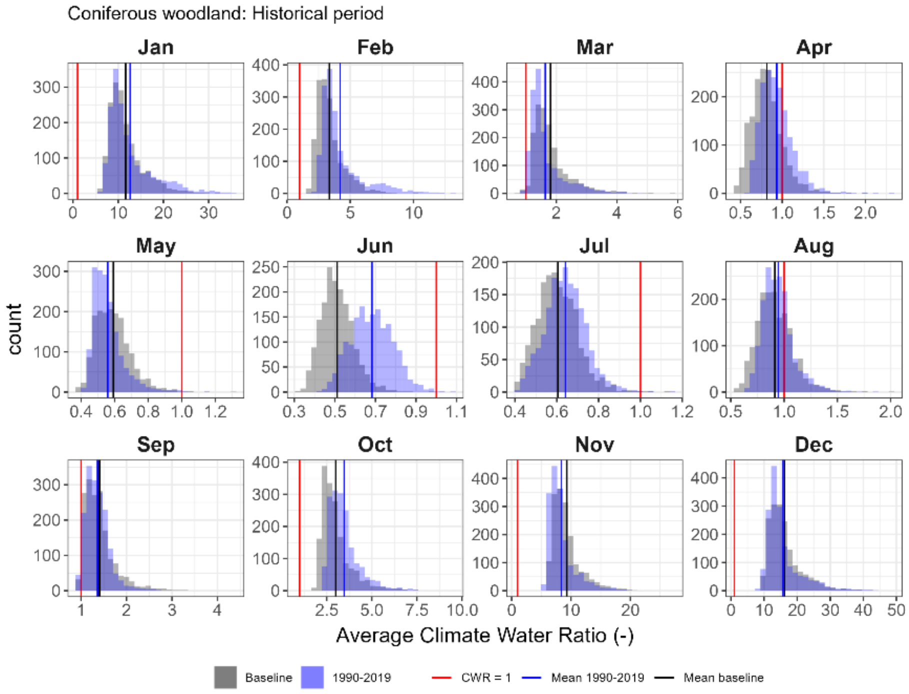


Figure 18. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Coniferous woodland in the 1990-2019 period.

- CWR was similar in coniferous woodland grid cells in the 1990 – 2019 period and the baseline period, with the exception of June, where coniferous grid cells were in smaller water stress in June compared to the baseline period. Overall, coniferous woodland grid cells were in small to moderate water stress from April to August for both time periods.

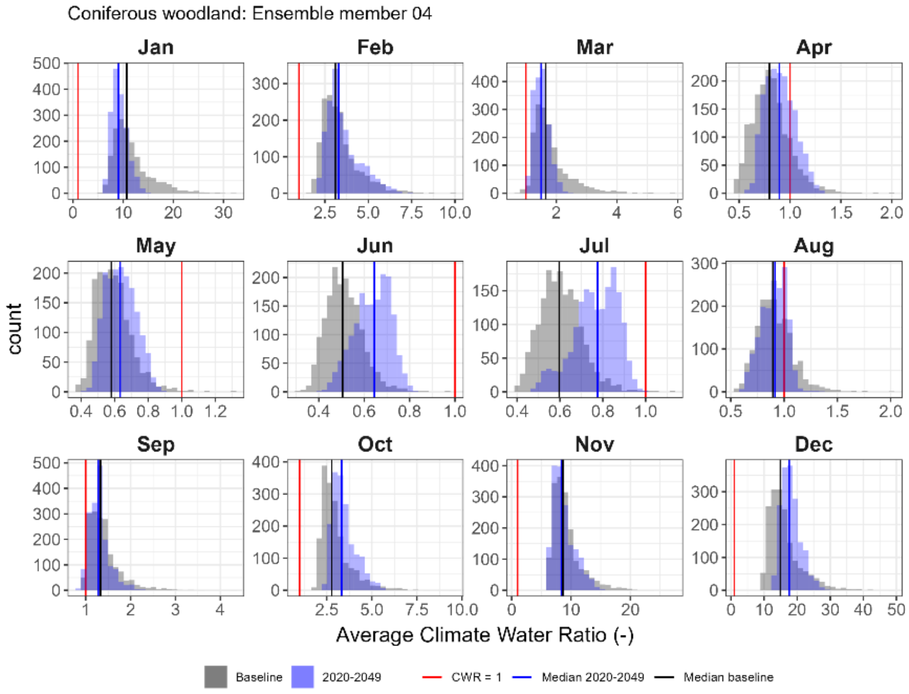


Figure 19. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Coniferous woodland for two future periods using Climate projection EM04 (wettest example).

- CWR was similar in coniferous woodland grid cells in the 2020 – 2049 period and the baseline period for most months, but water stress is smaller in the coniferous woodland grid cells compared to the baseline period in June and July.

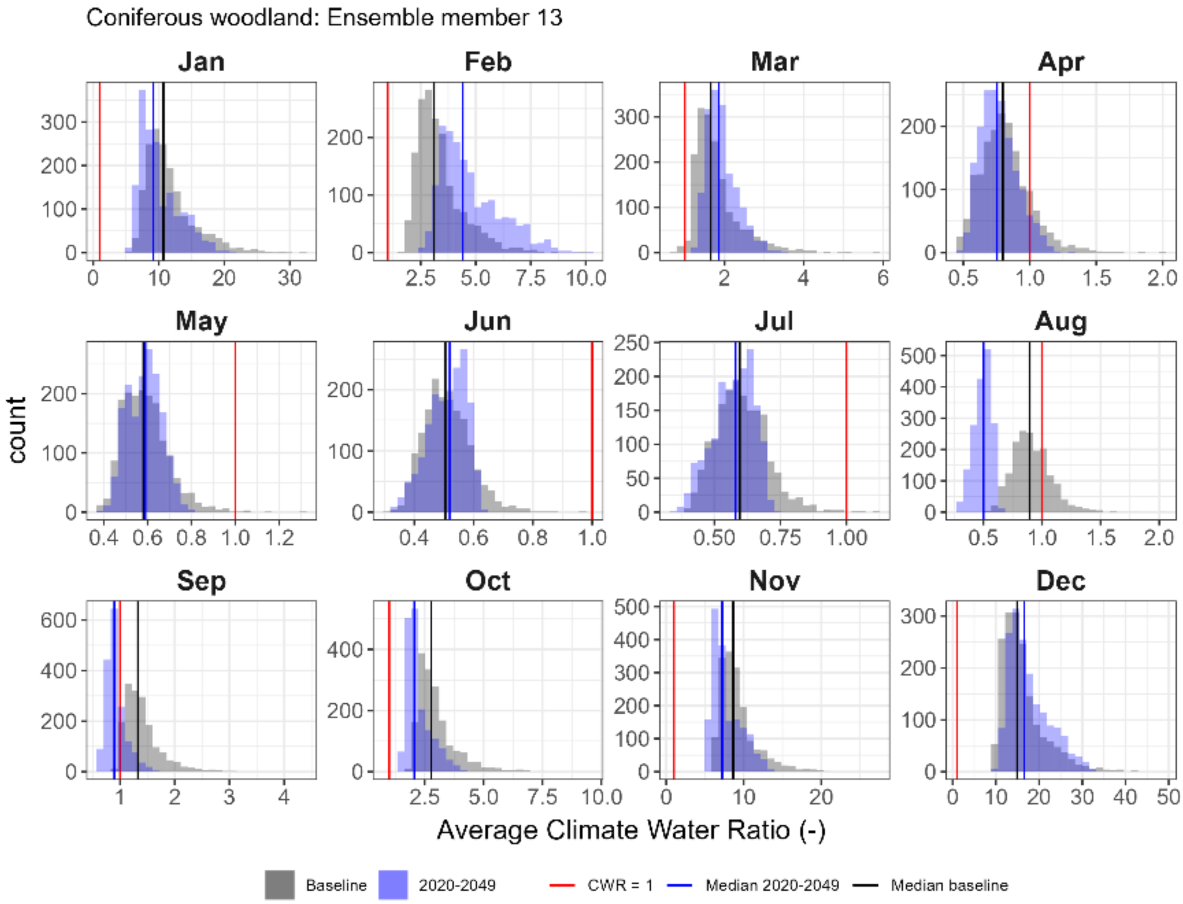


Figure 20. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Coniferous woodland for two future periods using Climate projection EM13 (driest example).

- CWR was similar in coniferous woodland grid cells in the 1990 – 2019 period and the baseline period for most of the year, including the mid spring to summer period, with the exception of August when around 40% of the coniferous woodland grid cells were in water surplus for the baseline period but all grid cells are in moderate to severe water stress for the 2020 – 2049 period.

Improved grassland

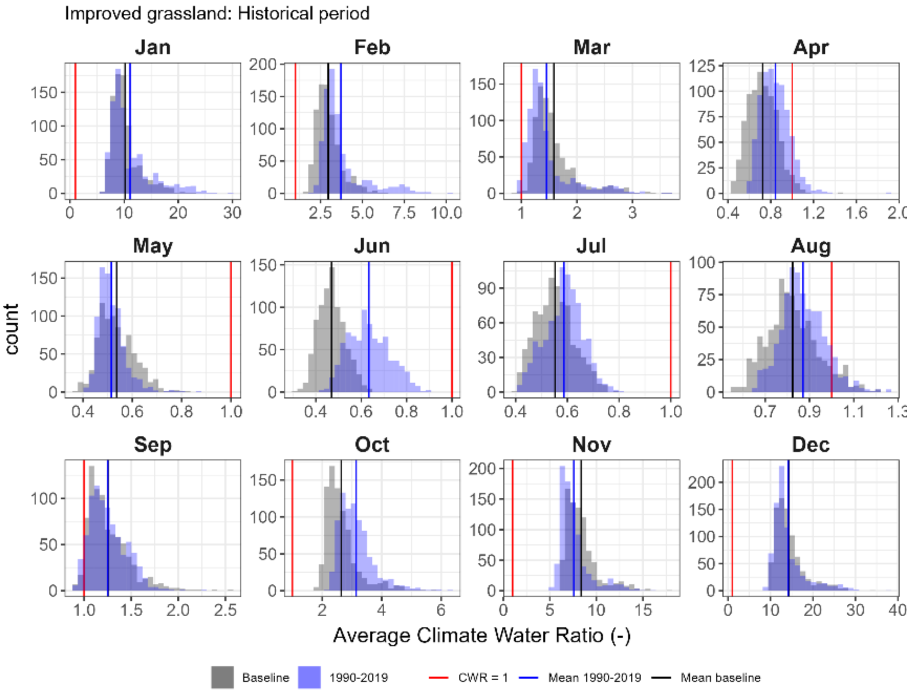


Figure 21. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Improved Grassland in the 1990-2019 period.

- CWR was overall similar in improved grassland grid cells for the 1990 – 2019 period and the baseline period for most months, with improved grassland grid cells being in moderate to severe water stress from April to August. However, water stress in June was smaller in these grid cells compared to the baseline period.

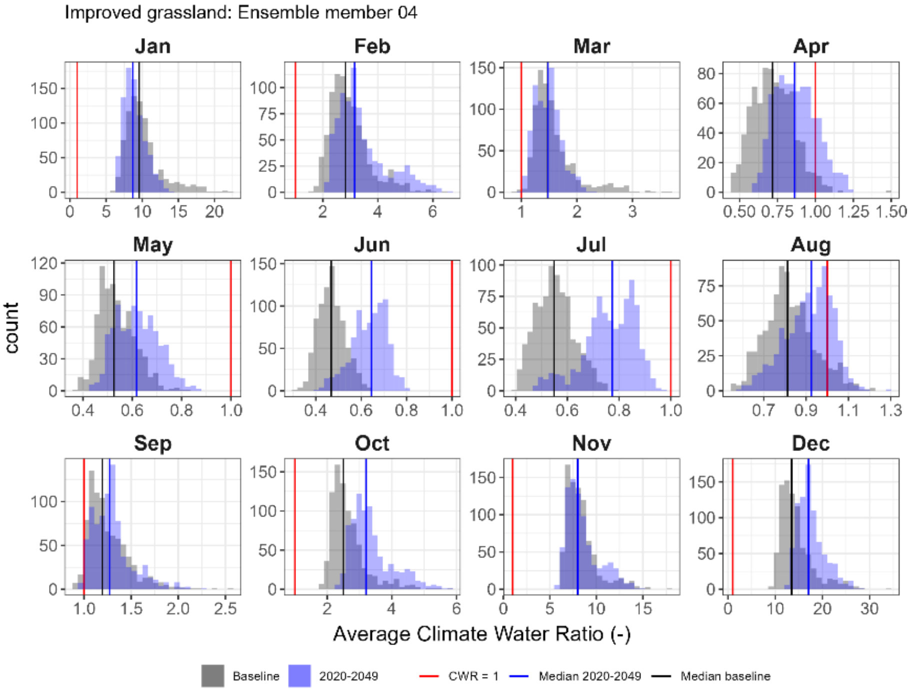


Figure 22. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Improved Grassland for two future periods using Climate projection EM04 (wettest example).

- Marked differences in CWR exist between the 2020 – 2049 and baseline periods from April to August, when moderate to severe water stress is observed. However, water stress in the improved grassland grid cells for these months is smaller for the 2020 – 2049 period compared to the baseline period.

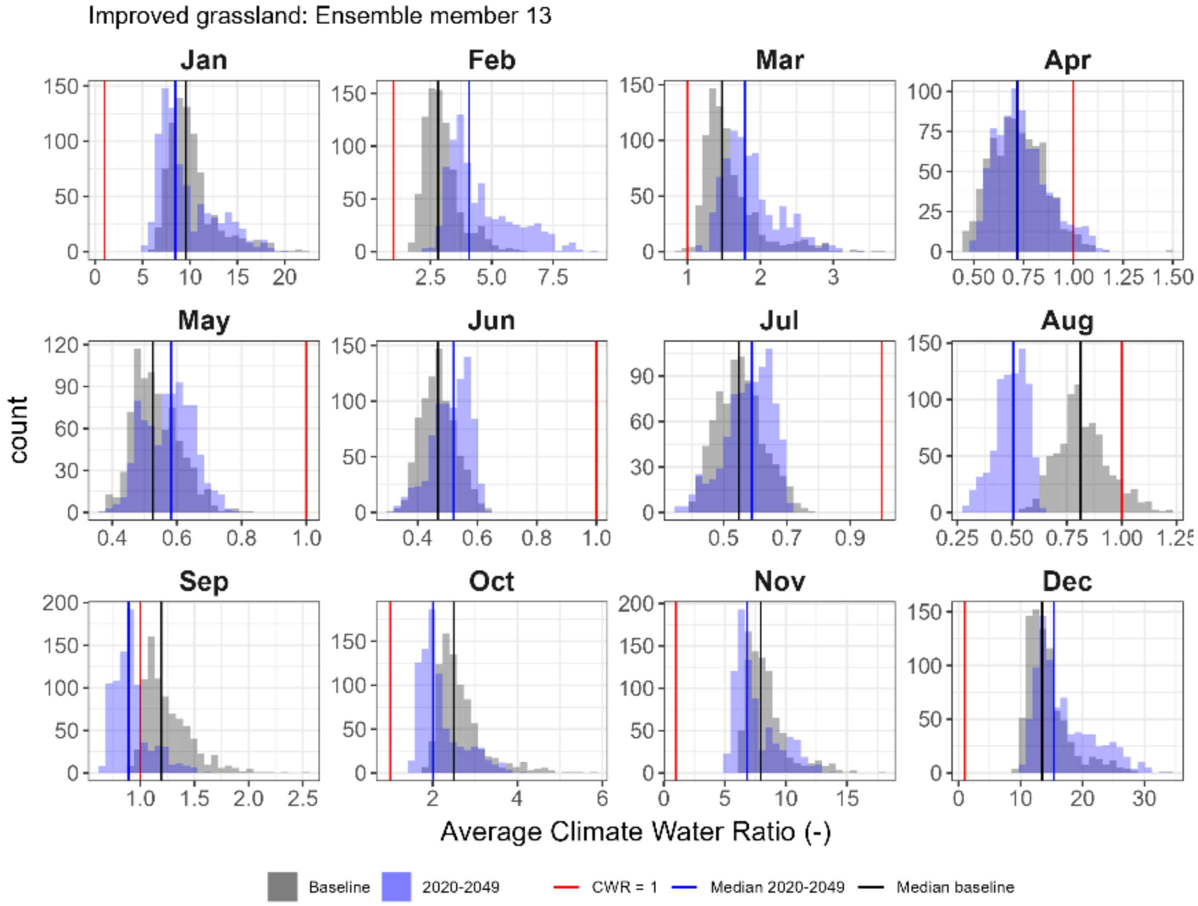


Figure 23. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Improved Grassland for two future periods using Climate projection EM13 (driest example).

- CWR is fairly similar in improved grassland grid cells for the 2020 – 2049 and baseline periods, apart from in August, where most improved grassland grid cells are in moderate to severe water stress for the 2020 – 2049 period but most of these cells are in small to moderate water stress for the baseline period.

Mountain, Heath, Bog

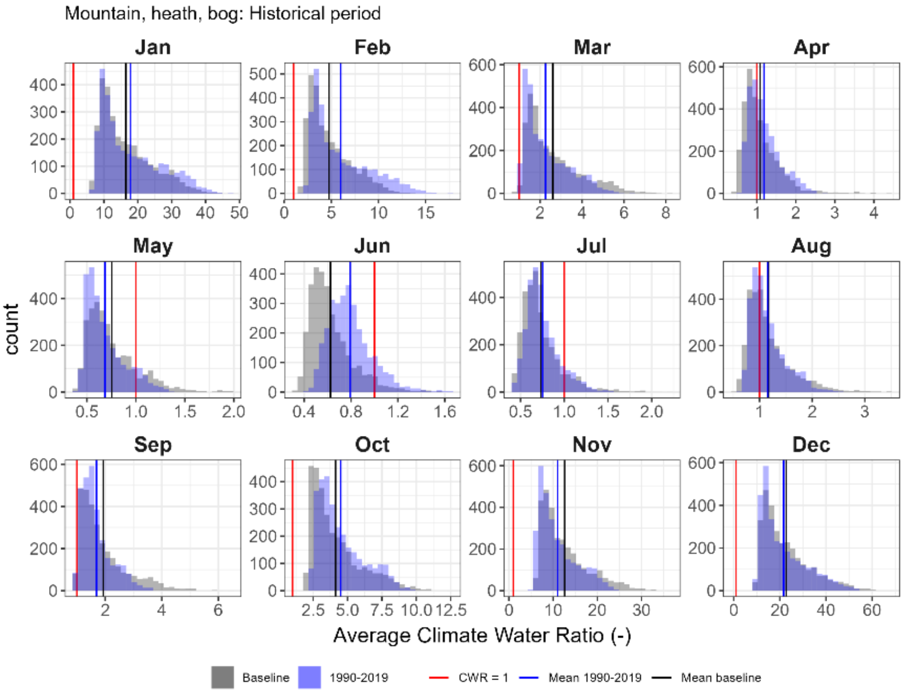


Figure 24. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Mountain, Heath and Bog in the 1990-2019 period.

- CWR was almost identical for all months for both periods (baseline and 1990 – 2019) in the heather moorland, peatland, and mountainous vegetation grid cells, with only water stress being smaller in June in these grid cells for the 1990 – 2019 period.

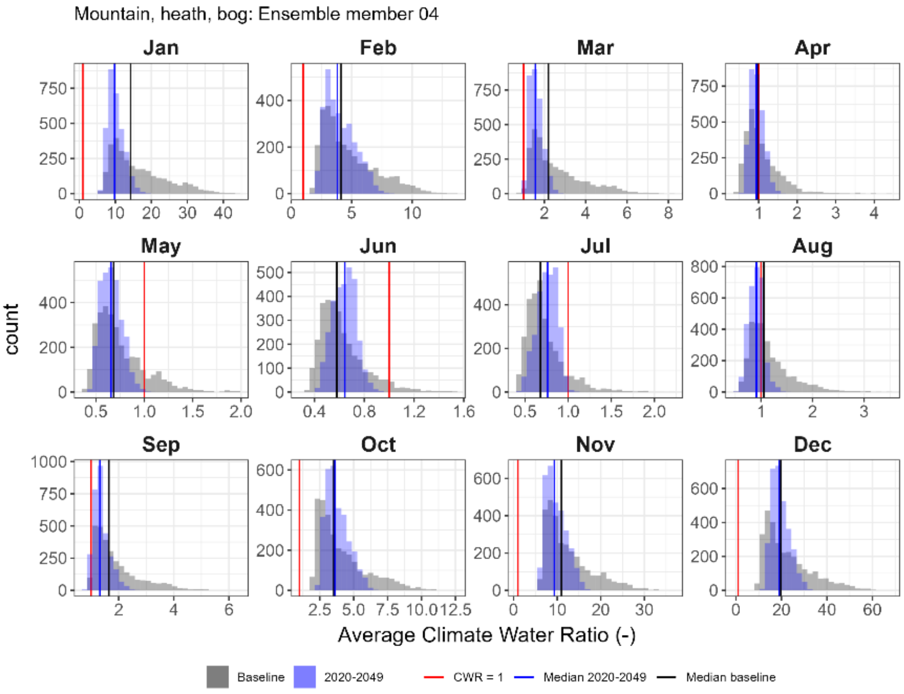


Figure 25. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Mountain, Heath and Bog for two future periods using Climate projection EM04 (wettest example).

- CWR is fairly similar for all months for both periods (baseline and 2020 – 2049) in the heather moorland, peatland, and mountainous vegetation grid cells, which were in water stress from May to August.

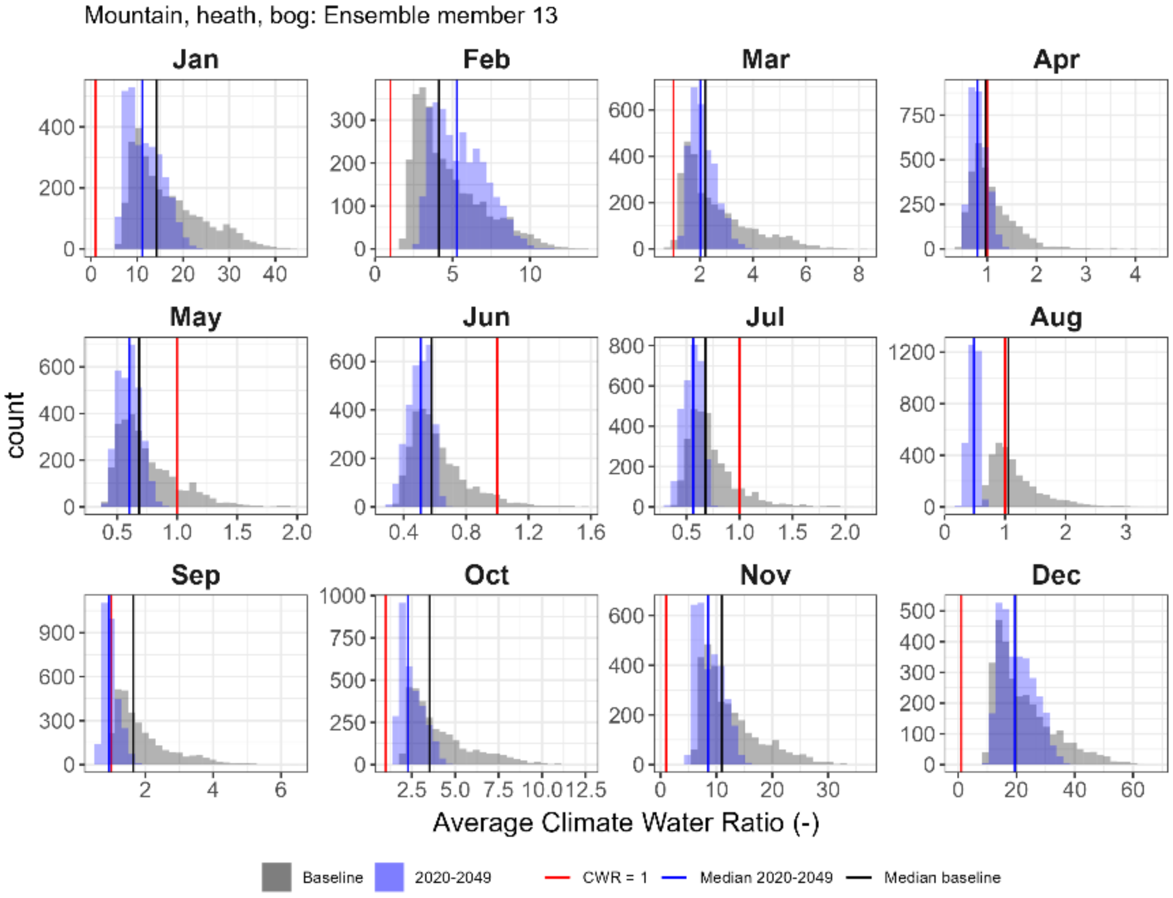


Figure 26. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Mountain, Heath and Bog for two future periods using Climate projection EM13 (driest example).

- CWR is fairly similar for all months for both periods (baseline and 2020 – 2049) in the heather moorland, peatland, and mountainous vegetation grid cells, with the exception of August, when all of these cells for the 2020 – 2049 period were in moderate to severe water stress compared almost half of the grid cells being in water surplus for the baseline period.

Seminatural grassland

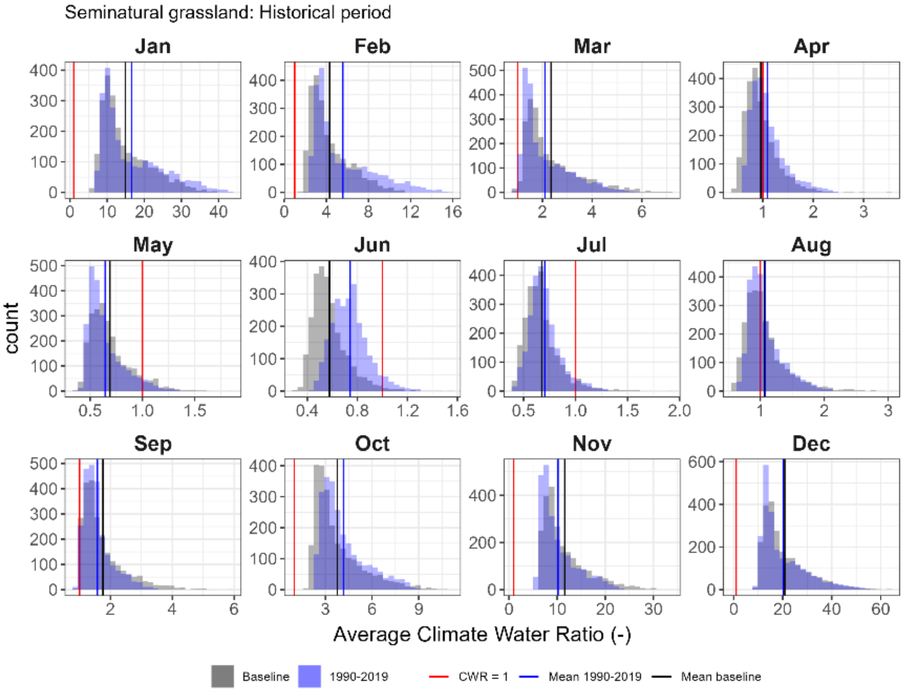


Figure 27. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Seminatural Grassland in the 1990-2019 period.

- CWR was fairly similar for all months for both periods (baseline and 1990 – 2019) in the seminatural grassland grid cells, with the exception of June when these cells are in smaller stress for the 1990 – 2019 period compared to the baseline period.

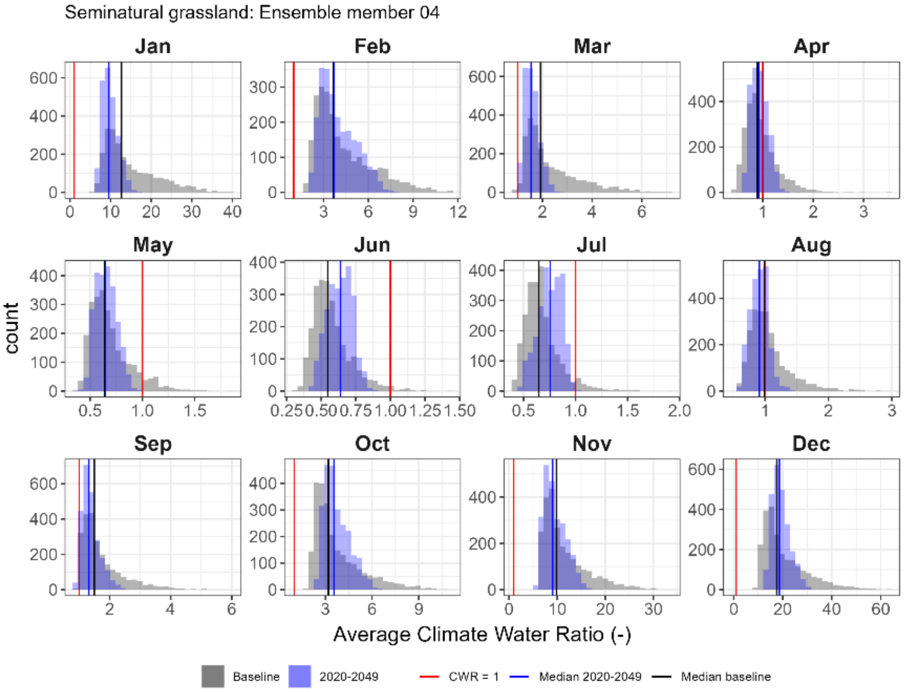


Figure 28. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Seminatural Grassland for two future periods using Climate projection EM04 (wettest example).

- CWR is fairly similar for all months for both periods (baseline and 2020 – 2049) in the seminatural grassland grid cells, with small differences observed in June and July when these cells are in smaller stress for the 2020 – 2049 period compared to the baseline period.

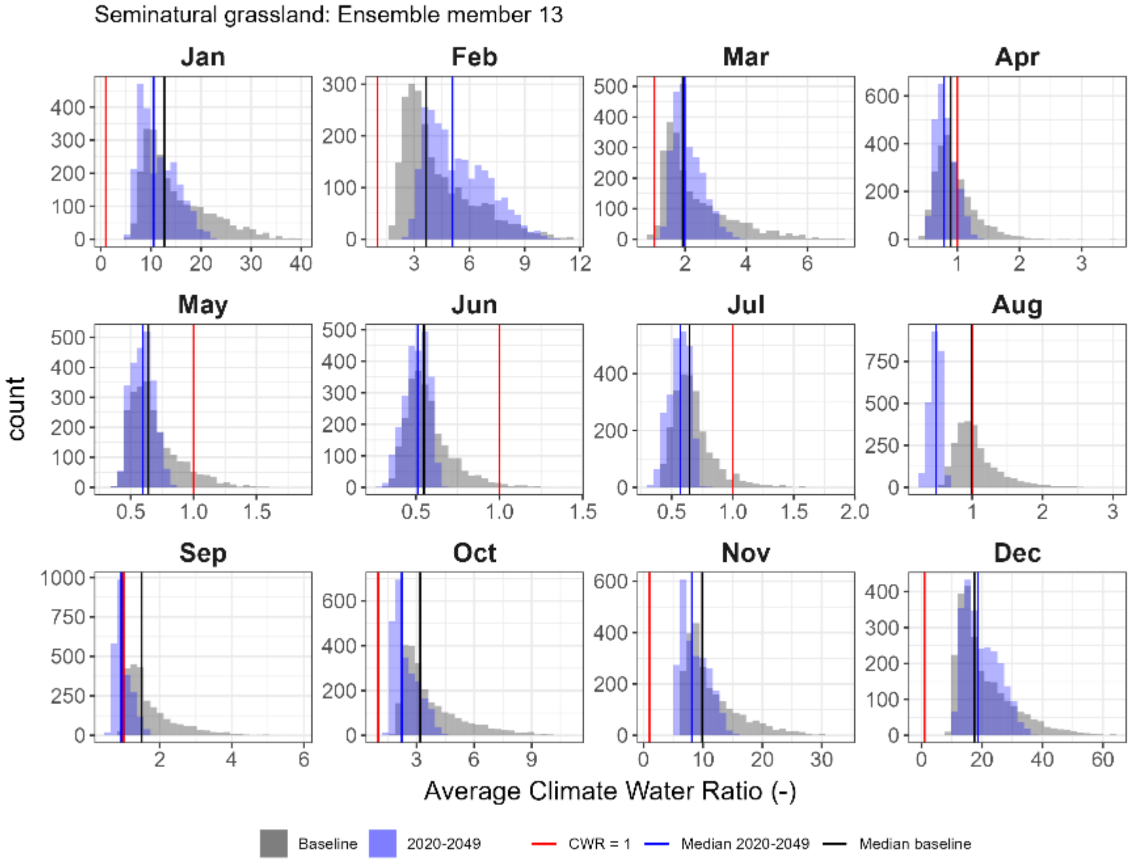


Figure 28. Spey catchment monthly Climatic Water Balance Ratios (CWR) for Seminatural Grassland for two future periods using Climate projection EM13 (driest example).

- CWR is fairly similar for all months for both periods (baseline and 2020 – 2049) in the seminatural grassland grid cells for most months. February is wetter in the seminatural grasslands for the 2020 – 2049 period compared to the baseline period, but drier in August when all seminatural grassland grid cells are in water stress for the 2020 -2049 period, while half of these cells are in water surplus for the baseline period.

Conclusions

- At a national level, observed shifts mainly from water surpluses to water deficits in late summer and early autumn are the main drivers of the degree of exposure for most habitat types, depending on their spatial distribution in relation to west vs east geographical distinction.
- In this context, arable land and to a lesser extent improved grasslands and broadleaf woodlands are the most exposed habitat types to climatic water stress. Monthly CWB is overall wetter for seminatural grasslands, heather moorlands, and peatlands, and to a lesser extent conifers, but it is of concern that water stress extends to early spring and late summer

(depending which future projections are used) because of the potential and substantial impacts on the ecological and hydrological functions of these NC assets.

- The Spey case study helped with exploring how climatic water balance ratios can be used to provide quantitative assessments of the degree of exposure of a given habitat to climatic water stress and also enable direct comparisons between different time periods. This approach proved to be useful at a catchment scale level for identifying the severity of climatic water stress and should be possible to be applied reasonably well at national scale.
- This spatial assessment has focussed on threats to Natural Capital from potential water deficits and surpluses, which can be built upon by adding further types of climatic threats, such as heat stress, to create a more detailed overall picture of risks.

Next Steps

This report provided analyses and visualisation techniques that provide quantitative assessments of the exposure of terrestrial habitat types in Scotland to the threat of meteorological drought in the form of climatic water stress. However, exposure does not consider the properties of a given NC asset at risk, but reflects the potential of a given place to be affected by a certain threat, in this case of meteorological drought, or the extent to which it is exposed to it. Hence, next steps need to focus on understanding the vulnerability of NC assets to specified threats by assessing the inherent properties or functioning of NC assets that define their resilience or coping capacity characteristics and, ultimately, their degree of vulnerability to the threat.

For example, the presence of high water tables in healthy (i.e., functioning) bogs can buffer against the effects of a prolonged climatic water stress, reducing their vulnerability to drought. In the case of the wildfire threat, plant physiology and soil characteristics (such as soil moisture) can increase the coping capacity of grasses, shrubs and trees (expressed by their fuel moisture) against the impacts of prolonged meteorological droughts and can reduce their vulnerability to the danger of fire ignition.

In this context, upcoming work[3] will focus on assessing the vulnerability of selected NC assets to threats such as meteorological drought and wildfires. Depending on data availability, we will explore available options such as using process-based or statistical modelling or developing semi-quantitative approaches (i.e., using matrices and weights based on expert opinion) with the aim to assess risks to NC asset functioning and the associated ability to deliver respective ecosystem services. We will also liaise with the D2-1 project team for considering drought propagation dynamics at catchment scales, from meteorological to hydrological and agricultural drought, and explore integrating multiple processes such as precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits and reduced groundwater contributions.

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[3] “D2.2a: Climate change effects on soil properties and functions” & “D2.4a: BBN models for wildland fire risk”.

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Appendix

Tables A1 – A7 give the proportions of each Aggregated Cover class by the change direction in Climatic Water Balance (CWB) classes for the observed period of 1990 – 2019 and summary statistics (mean (minimum – maximum)) proportions for the future periods of 2020 – 2049 and 2050 – 2079 using projected climate from all 12 Ensemble Members.

Table A1. Arable land

A) Period: 1990 - 2019				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0	0	100	0
Feb	0	0	100	0
Mar	1	16	64	19
Apr	1	99	0	0
May	0	100	0	0
June	0	100	0	0
July	0	100	0	0
Aug	1	98	2	0
Sep	3	43	34	20
Oct	0	0	100	0
Nov	0	0	100	0
Dec	0	0	100	0
B) Period: 2020 - 2049				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	11 (2-17)	6 (0-15)	74 (57-83)	9 (0-26)
Apr	6 (1-18)	94 (82-99)	0 (0-0)	0 (0-0)
May	0 (0-0)	100 (100-100)	0 (0-0)	0 (0-0)
June	0 (0-0)	100 (100-100)	0 (0-0)	0 (0-0)
July	0 (0-0)	100 (100-100)	0 (0-0)	0 (0-0)
Aug	0 (0-2)	98 (97-98)	0 (0-1)	2 (1-2)
Sep	2 (0-10)	45 (37-47)	14 (1-30)	40 (23-52)
Oct	0 (0-0)	0 (0-0)	99 (96-100)	1 (0-4)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
C) Period: 2050 - 2079				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	10 (5-17)	7 (0-12)	74 (60-82)	9 (1-23)
Apr	9 (0-28)	91 (72-100)	0 (0-0)	0 (0-0)
May	0 (0-0)	100 (100-100)	0 (0-0)	0 (0-0)
June	0 (0-0)	100 (100-100)	0 (0-0)	0 (0-0)
July	0 (0-0)	100 (100-100)	0 (0-0)	0 (0-0)
Aug	0 (0-0)	98 (98-98)	0 (0-0)	2 (2-2)

Sep	0 (0-1)	47 (46-47)	6 (2-14)	47 (39-51)
Oct	0 (0-0)	0 (0-0)	99 (90-100)	1 (0-10)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

Table A2. Broadleaf woodlands

A) Period: 1990 - 2019

Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0	0	100	0
Feb	0	0	100	0
Mar	0	4	89	6
Apr	11	69	19	0
May	3	94	3	0
June	3	95	1	0
July	3	89	7	1
Aug	5	64	29	1
Sep	2	15	74	9
Oct	0	0	100	0
Nov	0	0	100	0
Dec	0	0	100	0

B) Period: 2020 - 2049

Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	3 (1-5)	2 (0-4)	92 (84-95)	4 (0-12)
Apr	19 (7-38)	62 (43-74)	17 (12-19)	3 (0-7)
May	2 (0-7)	95 (90-97)	1 (0-2)	2 (1-3)
June	3 (0-8)	96 (91-99)	0 (0-1)	1 (1-1)
July	4 (1-9)	88 (83-91)	5 (2-8)	3 (1-6)
Aug	1 (0-6)	68 (63-70)	15 (7-23)	15 (7-23)
Sep	1 (0-5)	16 (13-17)	50 (25-69)	32 (13-58)
Oct	0 (0-0)	0 (0-0)	100 (99-100)	0 (0-1)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

C) Period: 2050 - 2079

Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	3 (1-5)	2 (0-3)	92 (86-95)	4 (0-9)
Apr	23 (2-45)	58 (36-78)	17 (9-19)	2 (0-10)
May	2 (0-6)	95 (91-97)	1 (0-2)	3 (1-3)
June	1 (0-4)	98 (95-99)	0 (0-0)	1 (1-1)
July	2 (1-6)	90 (86-91)	3 (1-7)	5 (1-7)
Aug	0 (0-0)	70 (69-70)	11 (5-15)	19 (16-25)
Sep	0 (0-0)	17 (17-17)	39 (29-55)	44 (28-54)
Oct	0 (0-0)	0 (0-0)	100 (98-100)	0 (0-2)

Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

Table A3. Coniferous woodlands

A) Period: 1990 - 2019				
Month	Deficit->Surplus	Deficit->Deficit	Surplus->Surplus	Surplus->Deficit
Jan	0	0	100	0
Feb	0	0	100	0
Mar	0	1	98	1
Apr	18	37	44	1
May	4	86	9	1
June	9	87	4	0
July	8	76	16	1
Aug	8	36	55	1
Sep	1	2	96	1
Oct	0	0	100	0
Nov	0	0	100	0
Dec	0	0	100	0
B) Period: 2020 - 2049				
Month	Deficit->Surplus	Deficit->Deficit	Surplus->Surplus	Surplus->Deficit
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	1 (0-1)	0 (0-1)	98 (95-99)	1 (0-4)
Apr	15 (5-31)	41 (25-51)	35 (23-42)	9 (2-21)
May	1 (0-4)	88 (86-90)	2 (0-6)	8 (5-10)
June	3 (0-7)	93 (89-96)	1 (0-2)	3 (2-4)
July	2 (0-5)	82 (79-83)	8 (3-14)	8 (3-13)
Aug	1 (0-4)	42 (39-43)	19 (7-37)	38 (19-50)
Sep	0 (0-1)	3 (2-3)	64 (33-87)	34 (10-65)
Oct	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
C) Period: 2050 - 2079				
Month	Deficit->Surplus	Deficit->Deficit	Surplus->Surplus	Surplus->Deficit
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	1 (0-1)	0 (0-1)	98 (93-99)	1 (0-6)
Apr	18 (2-35)	38 (21-54)	36 (17-43)	8 (1-28)
May	1 (0-4)	89 (85-90)	2 (0-5)	9 (5-10)
June	1 (0-2)	95 (94-96)	0 (0-1)	4 (3-4)
July	1 (0-3)	83 (81-84)	4 (1-12)	12 (5-16)
Aug	0 (0-0)	43 (43-43)	12 (4-16)	45 (41-52)
Sep	0 (0-0)	3 (3-3)	49 (38-67)	48 (30-59)
Oct	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

Table A4. Improved grassland

A) Period: 1990 - 2019				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0	0	100	0
Feb	0	0	100	0
Mar	0	2	94	4
Apr	9	79	9	2
May	1	99	0	0
June	0	99	0	0
July	0	97	2	1
Aug	7	70	20	4
Sep	1	10	81	8
Oct	0	0	100	0
Nov	0	0	100	0
Dec	0	0	100	0
B) Period: 2020 - 2049				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	1 (0-2)	1 (0-2)	95 (89-98)	3 (0-9)
Apr	19 (4-41)	70 (48-84)	7 (3-10)	5 (2-8)
May	1 (0-1)	99 (98-100)	0 (0-0)	0 (0-1)
June	1 (0-2)	99 (98-100)	0 (0-0)	0 (0-0)
July	1 (0-3)	96 (94-97)	1 (0-2)	2 (1-3)
Aug	2 (0-7)	75 (69-76)	6 (2-12)	18 (12-22)
Sep	1 (0-3)	10 (8-11)	51 (17-74)	38 (15-72)
Oct	0 (0-0)	0 (0-0)	100 (99-100)	0 (0-1)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
C) Period: 2050 - 2079				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	1 (1-2)	1 (0-1)	95 (89-98)	3 (0-9)
Apr	23 (1-50)	66 (39-87)	7 (2-10)	5 (2-10)
May	0 (0-1)	99 (98-100)	0 (0-0)	1 (0-1)
June	0 (0-1)	99 (98-100)	0 (0-0)	0 (0-0)
July	1 (0-2)	96 (95-97)	1 (0-2)	2 (1-3)
Aug	0 (0-0)	76 (76-76)	4 (2-5)	20 (19-22)
Sep	0 (0-0)	11 (11-11)	38 (24-58)	51 (31-65)
Oct	0 (0-0)	0 (0-0)	100 (98-100)	0 (0-2)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

Table A5. Mountain, Heath, Bog

A) Period: 1990 - 2019				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0	0	100	0
Feb	0	0	100	0
Mar	0	0	100	0
Apr	13	18	67	2
May	5	72	18	5
June	6	79	13	2
July	4	67	25	4
Aug	7	18	72	2
Sep	0	0	99	0
Oct	0	0	100	0
Nov	0	0	100	0
Dec	0	0	100	0
B) Period: 2020 - 2049				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	0 (0-0)	0 (0-0)	100 (98-100)	0 (0-2)
Apr	7 (0-28)	20 (1-43)	48 (13-93)	24 (2-54)
May	2 (0-13)	64 (12-92)	5 (0-26)	29 (7-88)
June	3 (0-24)	76 (44-97)	6 (0-28)	15 (2-51)
July	4 (0-18)	61 (27-90)	15 (1-39)	20 (5-58)
Aug	1 (0-11)	22 (3-39)	29 (2-66)	48 (18-77)
Sep	0 (0-0)	0 (0-0)	77 (28-99)	23 (1-72)
Oct	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
C) Period: 2050 - 2079				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	0 (0-0)	0 (0-0)	100 (97-100)	0 (0-3)
Apr	9 (0-31)	19 (1-44)	50 (6-94)	22 (1-68)
May	1 (0-13)	65 (12-92)	5 (0-26)	30 (7-88)
June	2 (0-18)	77 (45-97)	4 (0-17)	18 (2-52)
July	2 (0-15)	63 (28-90)	10 (0-34)	25 (5-64)
Aug	0 (0-1)	23 (4-39)	23 (2-57)	55 (27-82)
Sep	0 (0-0)	0 (0-0)	63 (27-93)	37 (7-73)
Oct	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

Table A6. Seminatural grassland

A) Period: 1990 - 2019				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0	0	100	0
Feb	0	0	100	0
Mar	0	0	100	0
Apr	12	21	67	0
May	3	54	38	5
June	12	60	27	0
July	7	53	40	1
Aug	5	20	74	0
Sep	0	0	99	1
Oct	0	0	100	0
Nov	0	0	100	0
Dec	0	0	100	0
B) Period: 2020 - 2049				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	0 (0-2)	0 (0-1)	99 (84-100)	1 (0-14)
Apr	16 (0-79)	44 (2-100)	21 (0-66)	19 (0-95)
May	0 (0-3)	89 (55-100)	2 (0-22)	8 (0-42)
June	1 (0-6)	92 (67-100)	2 (0-17)	5 (0-26)
July	1 (0-3)	89 (56-100)	5 (0-32)	5 (0-30)
Aug	1 (0-4)	65 (24-100)	9 (0-53)	26 (0-64)
Sep	0 (0-3)	1 (0-3)	63 (0-100)	37 (0-100)
Oct	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
C) Period: 2050 - 2079				
Month	**Deficit->Surplus**	**Deficit->Deficit**	**Surplus->Surplus**	**Surplus->Deficit**
Jan	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Feb	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Mar	0 (0-2)	0 (0-1)	99 (87-100)	0 (0-11)
Apr	20 (0-79)	39 (2-100)	22 (0-66)	19 (0-95)
May	0 (0-3)	89 (55-100)	2 (0-21)	9 (0-42)
June	0 (0-2)	93 (70-100)	1 (0-9)	6 (0-27)
July	0 (0-2)	90 (58-100)	3 (0-27)	7 (0-37)
Aug	0 (0-3)	65 (25-100)	6 (0-33)	29 (0-65)
Sep	0 (0-1)	1 (0-3)	46 (0-100)	53 (0-100)
Oct	0 (0-0)	0 (0-0)	100 (99-100)	0 (0-1)
Nov	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)
Dec	0 (0-0)	0 (0-0)	100 (100-100)	0 (0-0)

Figures A1 – A25 give the area proportions for the monthly change direction in Climatic Water Balance (CWB) for the selected Aggregated Cover Classes and the periods 2020 – 2049 and 2050 – 2079 relative to the baseline period 1960-1989 using climate projections from all 12 Ensemble Members.

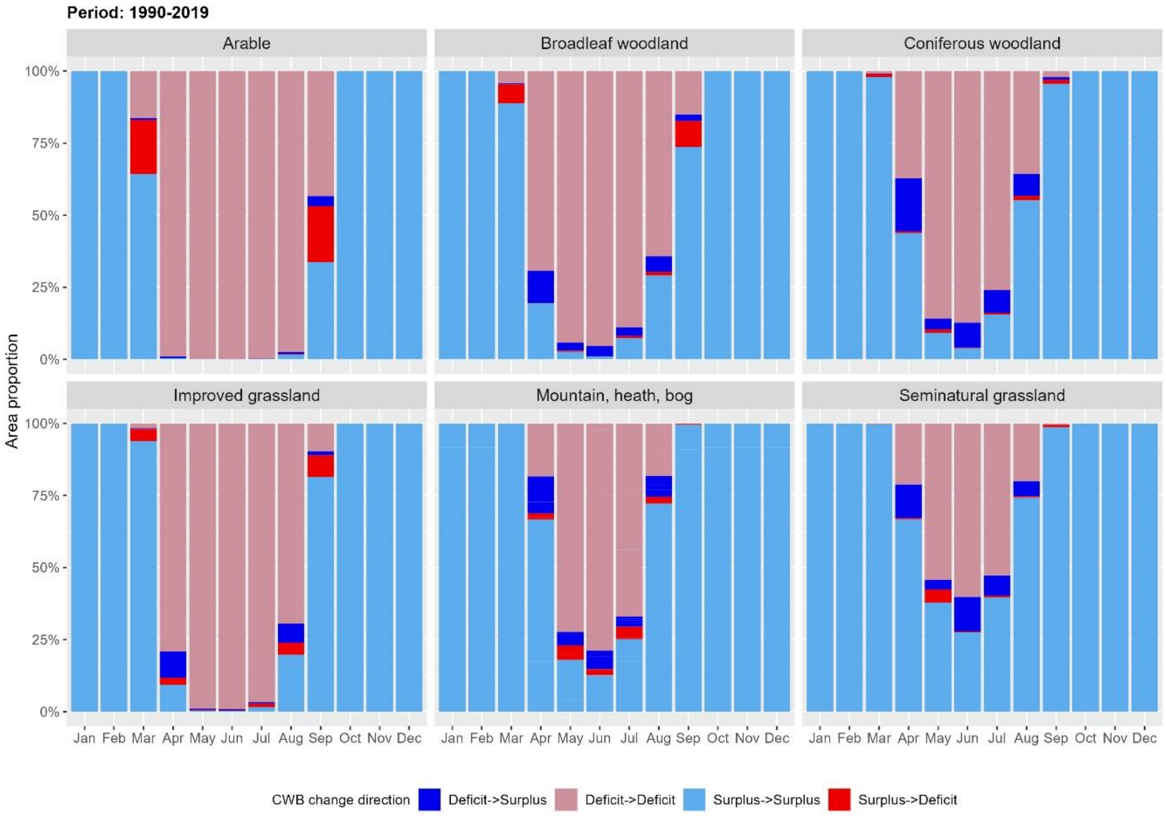

Figure A1. Area proportions for monthly change direction in CWB for Aggregated Cover Classes for the 1990 – 2019 period relative to the baseline period 1960-1989.

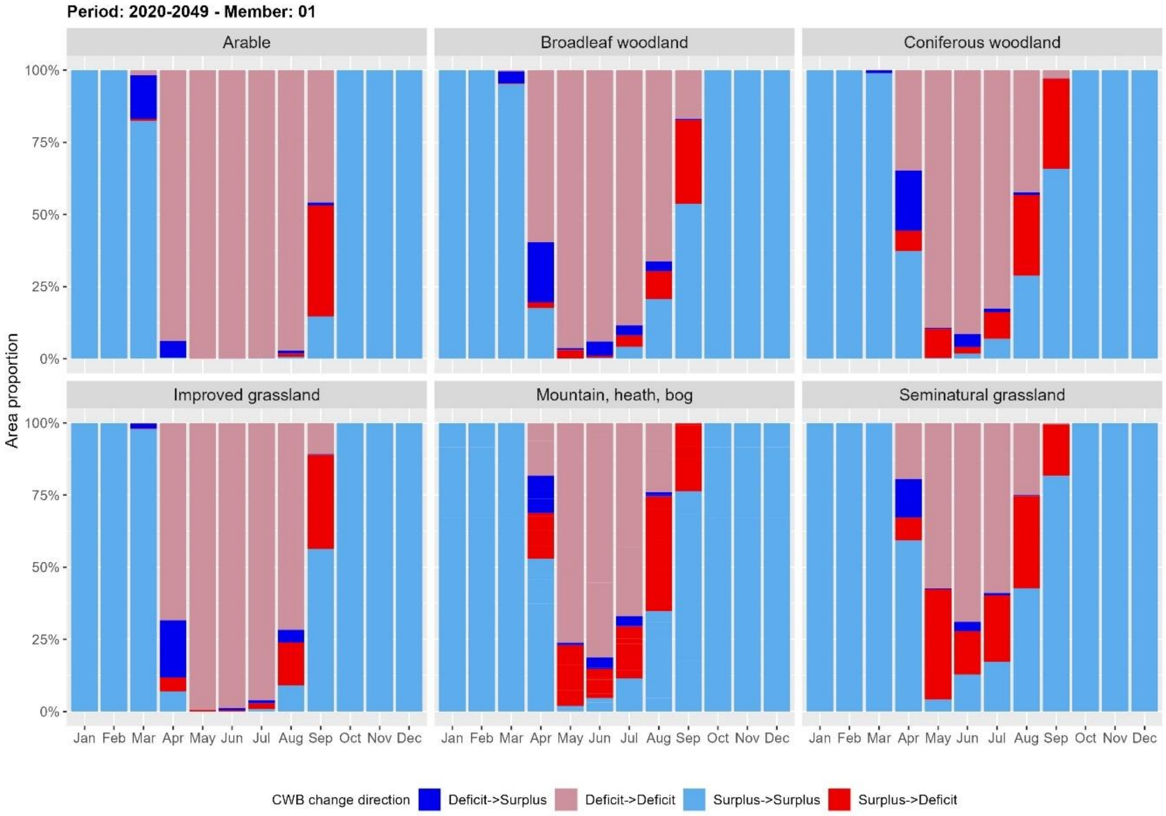

Figure A2. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM01.

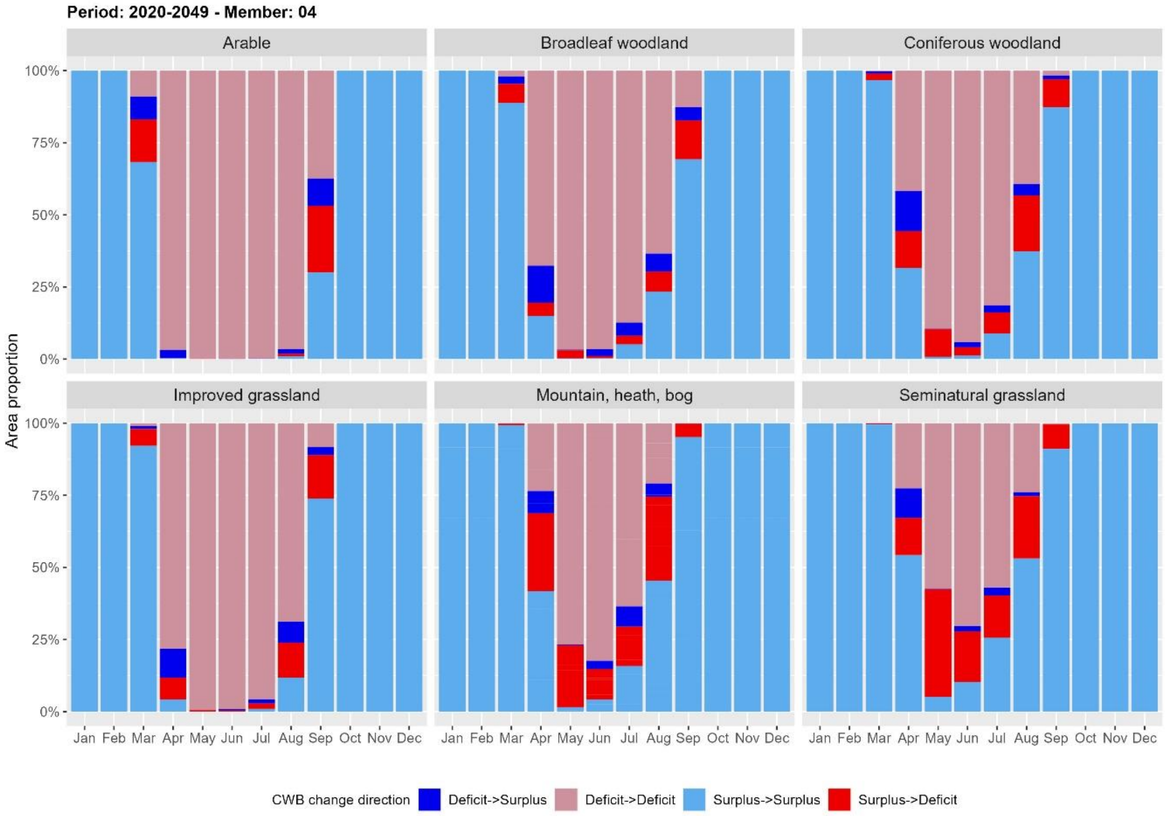

Figure A3. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM04.

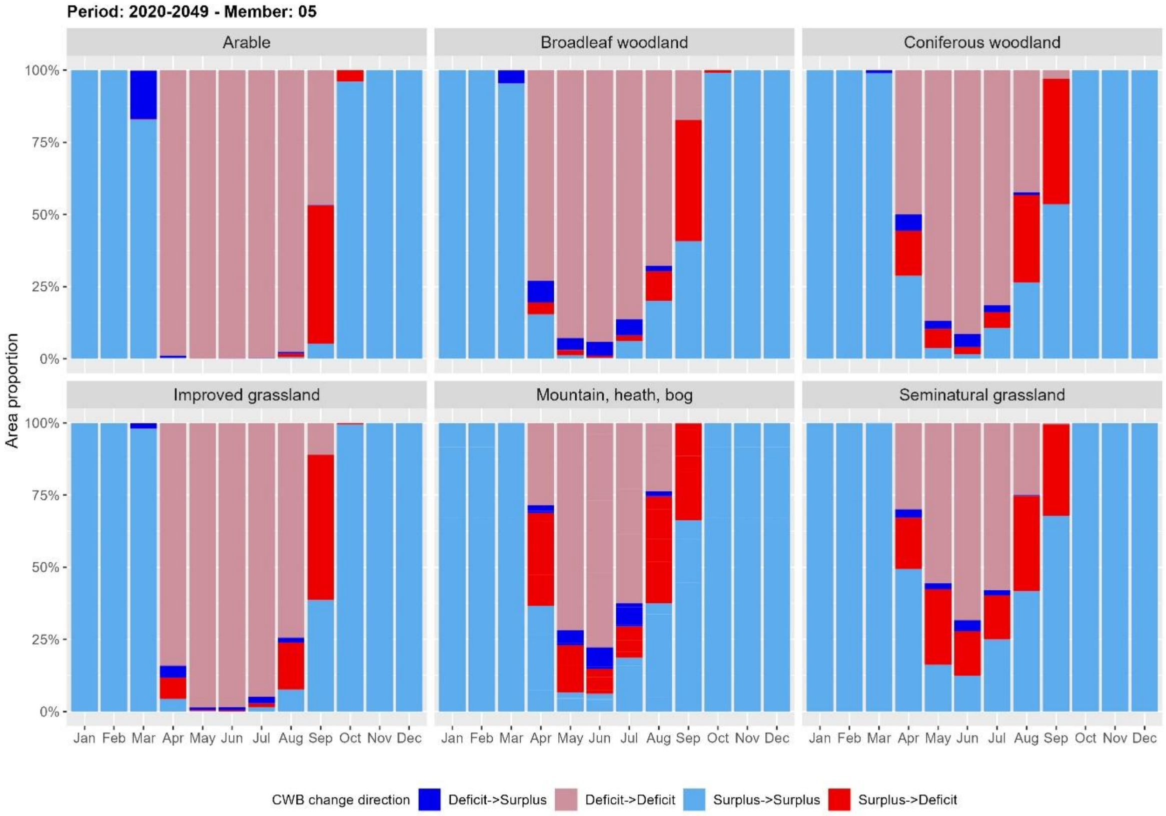

Figure A4. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM05.

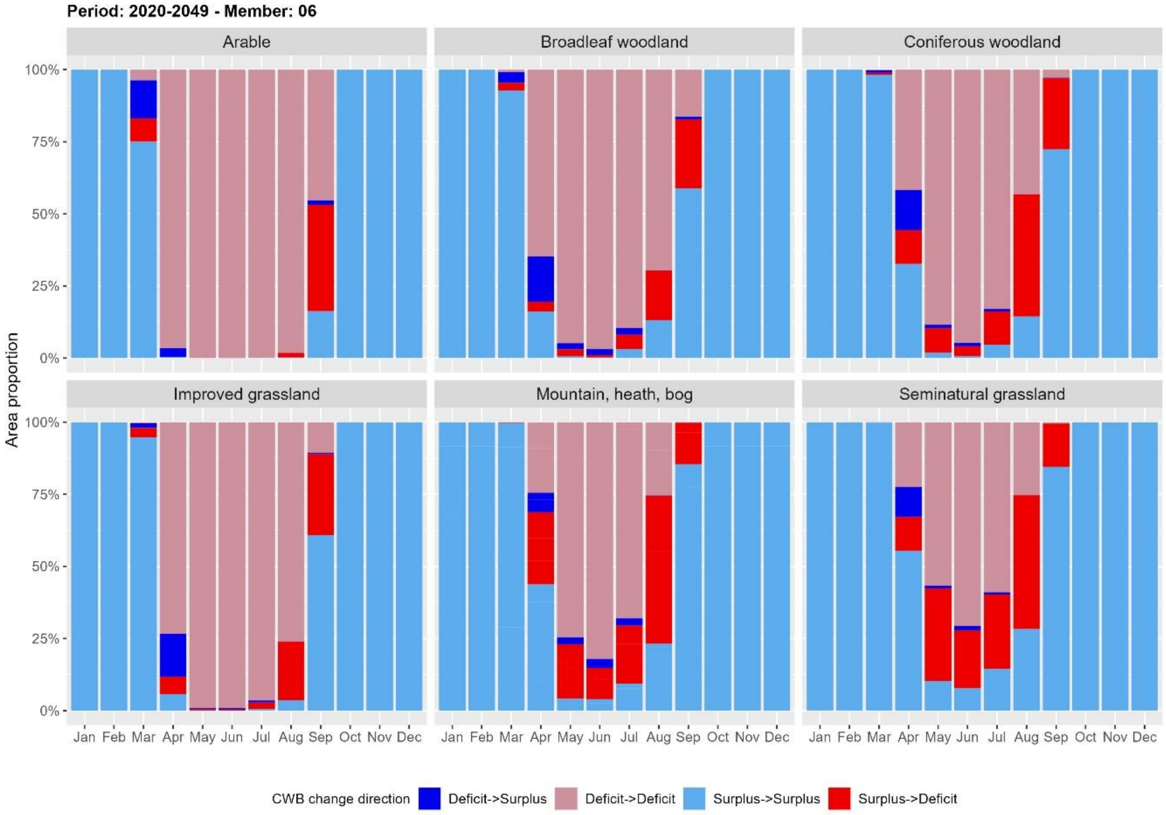

Figure A5. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM06.

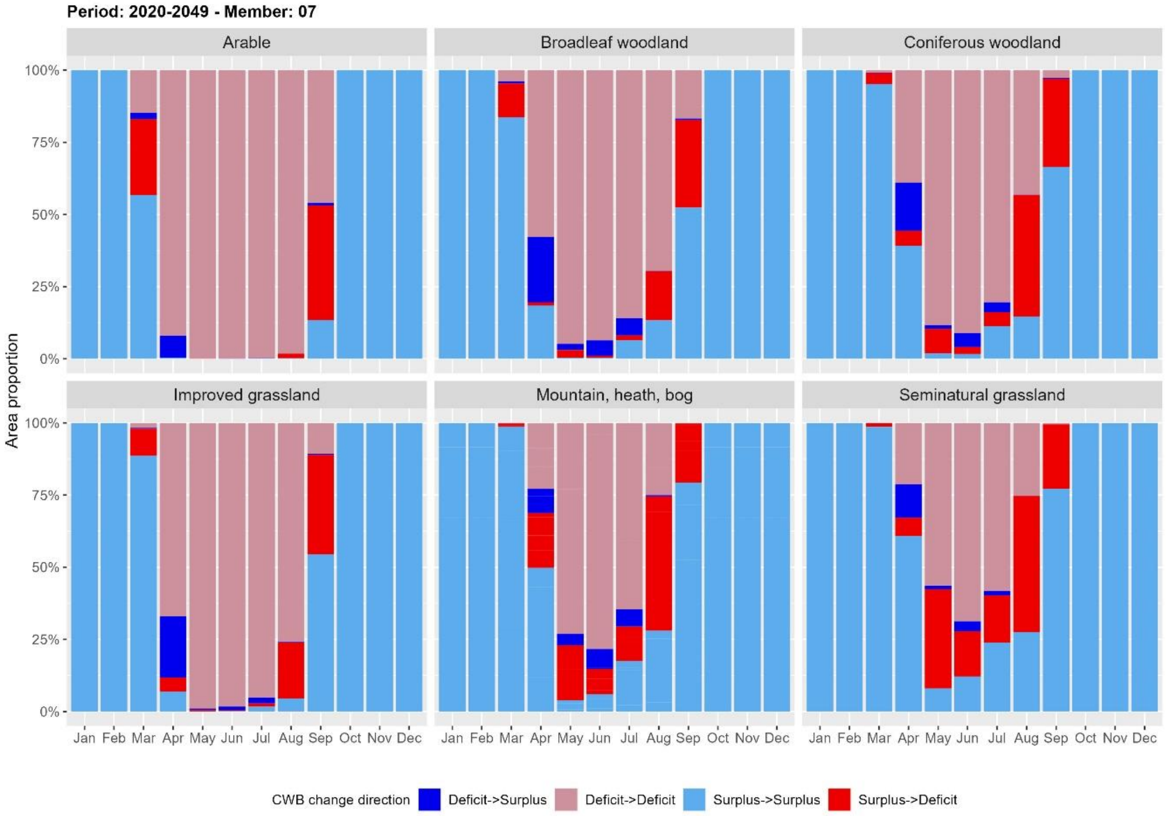

Figure A6. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM07.

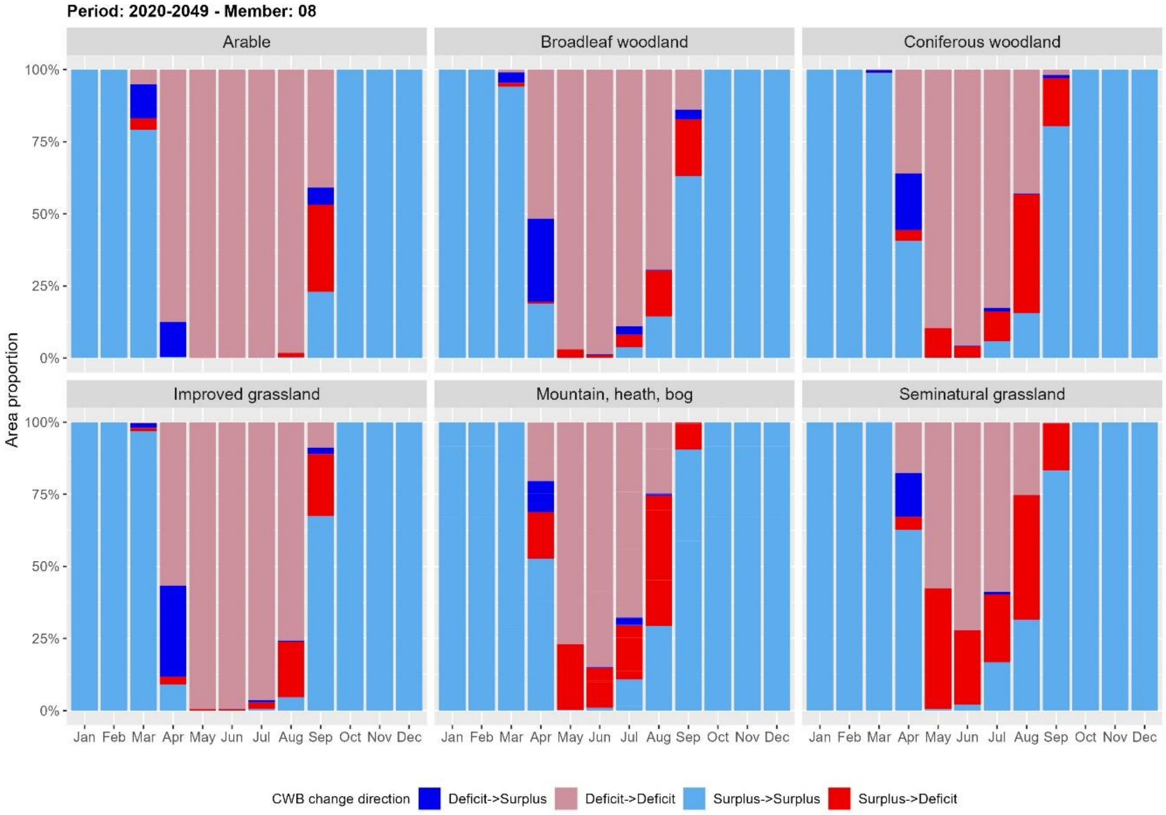

Figure A7. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM08.

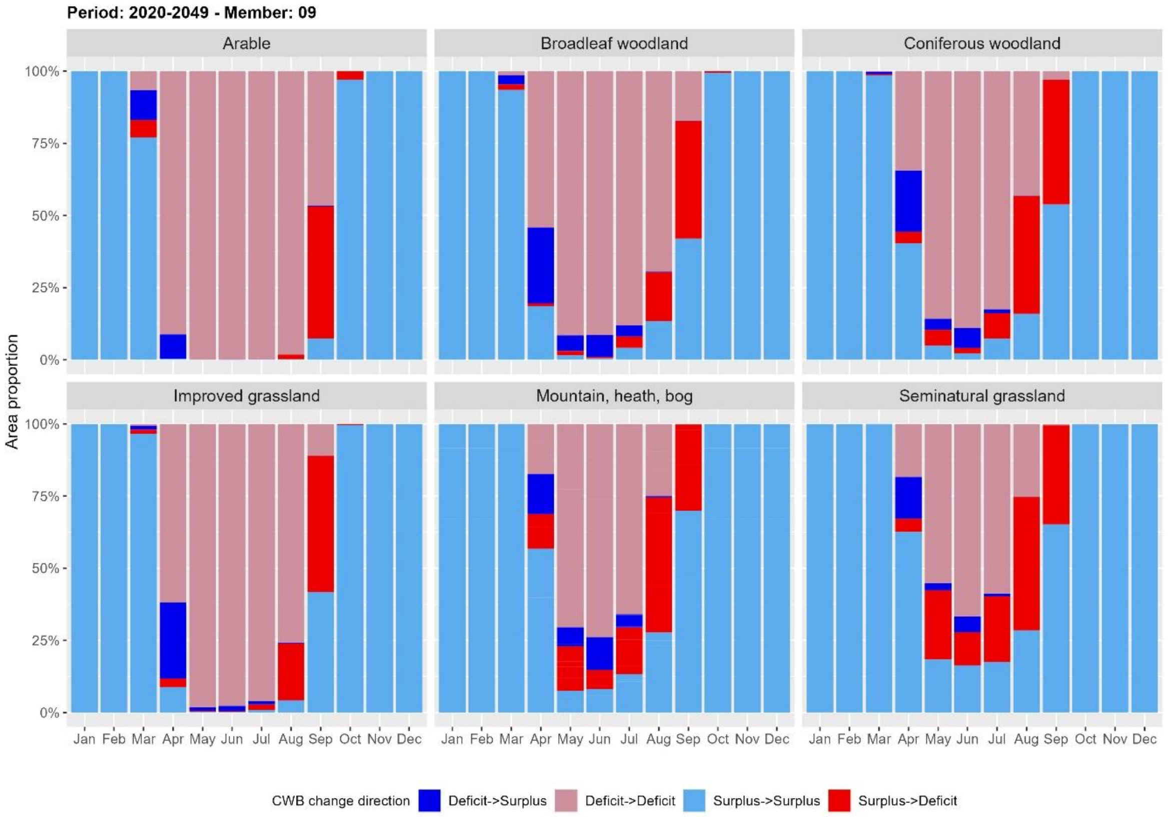

Figure A8. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM09.

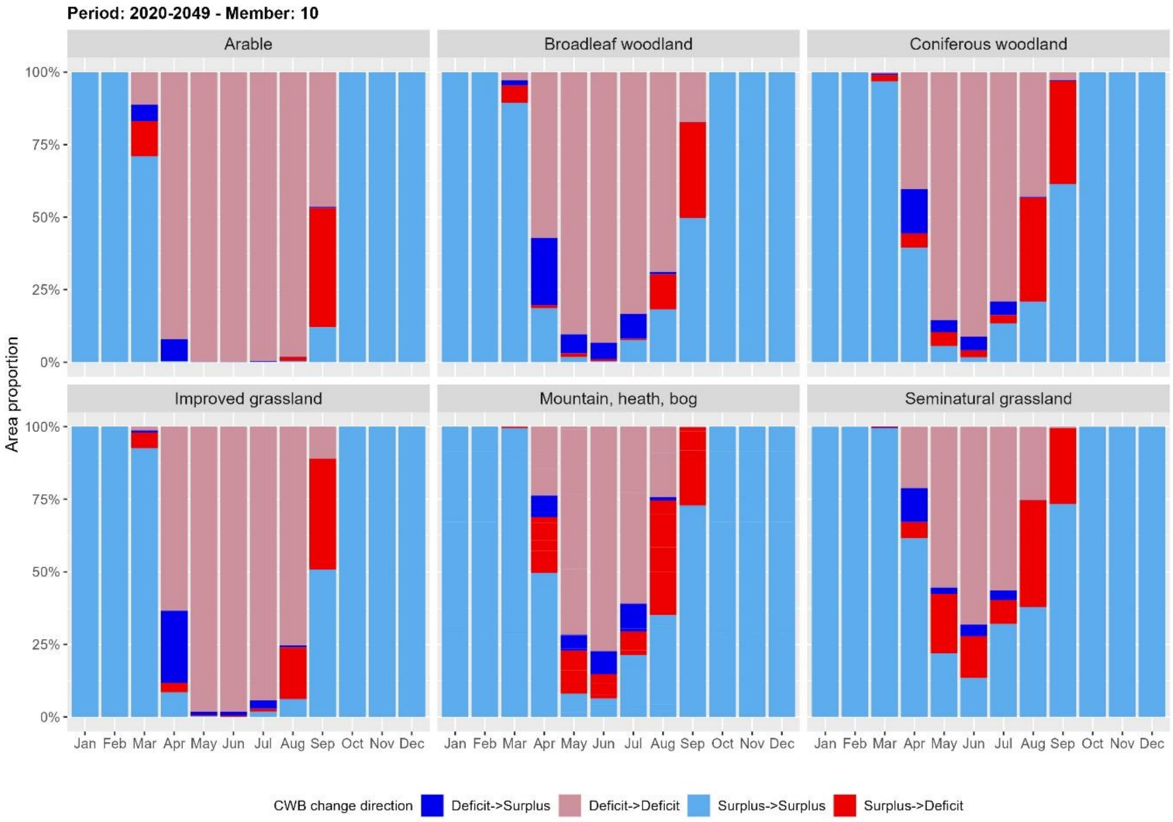

Figure A9. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM010.

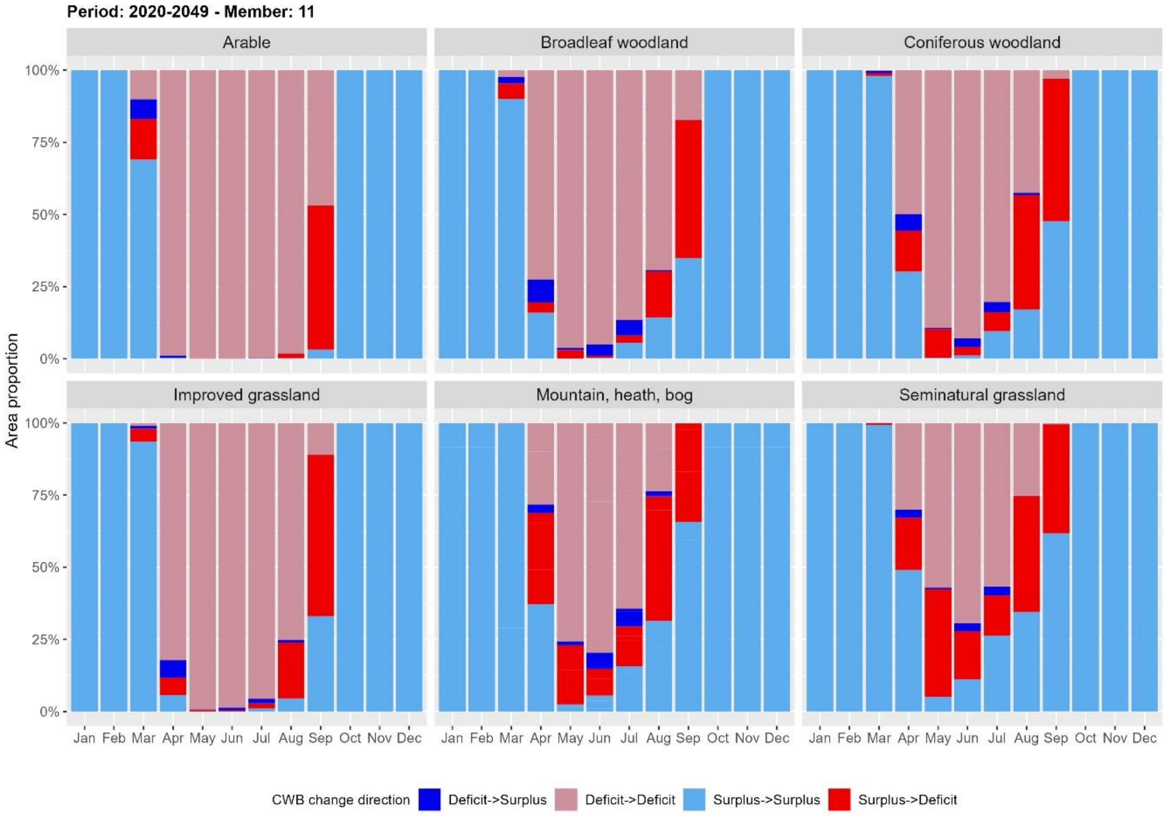

Figure A10. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM11.

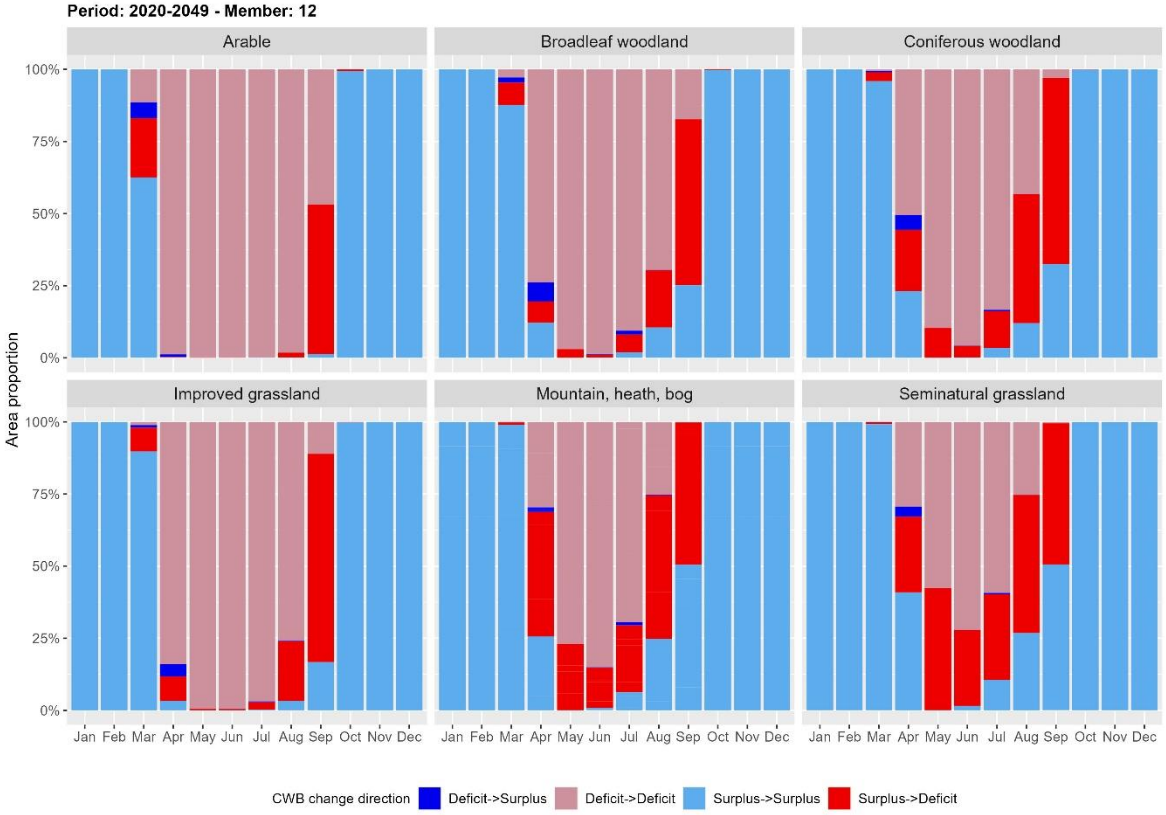

Figure A11. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM12.

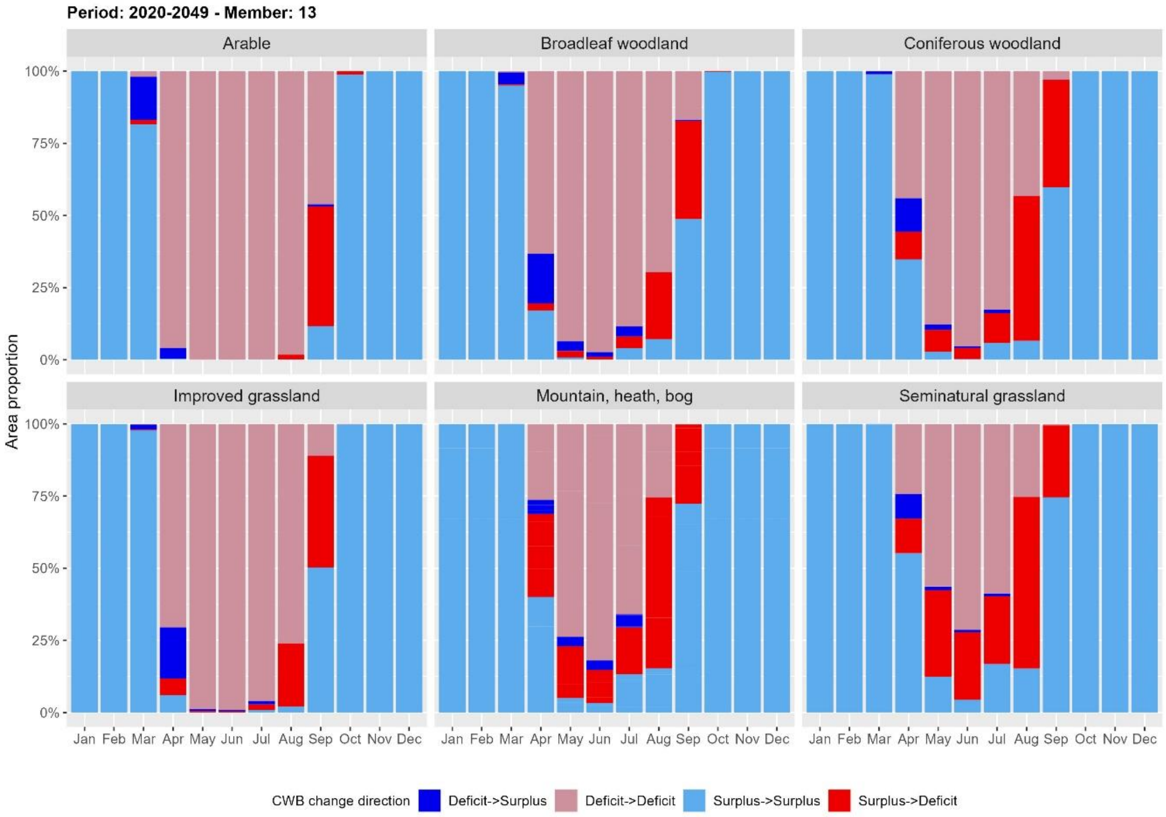

Figure A12. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM13.

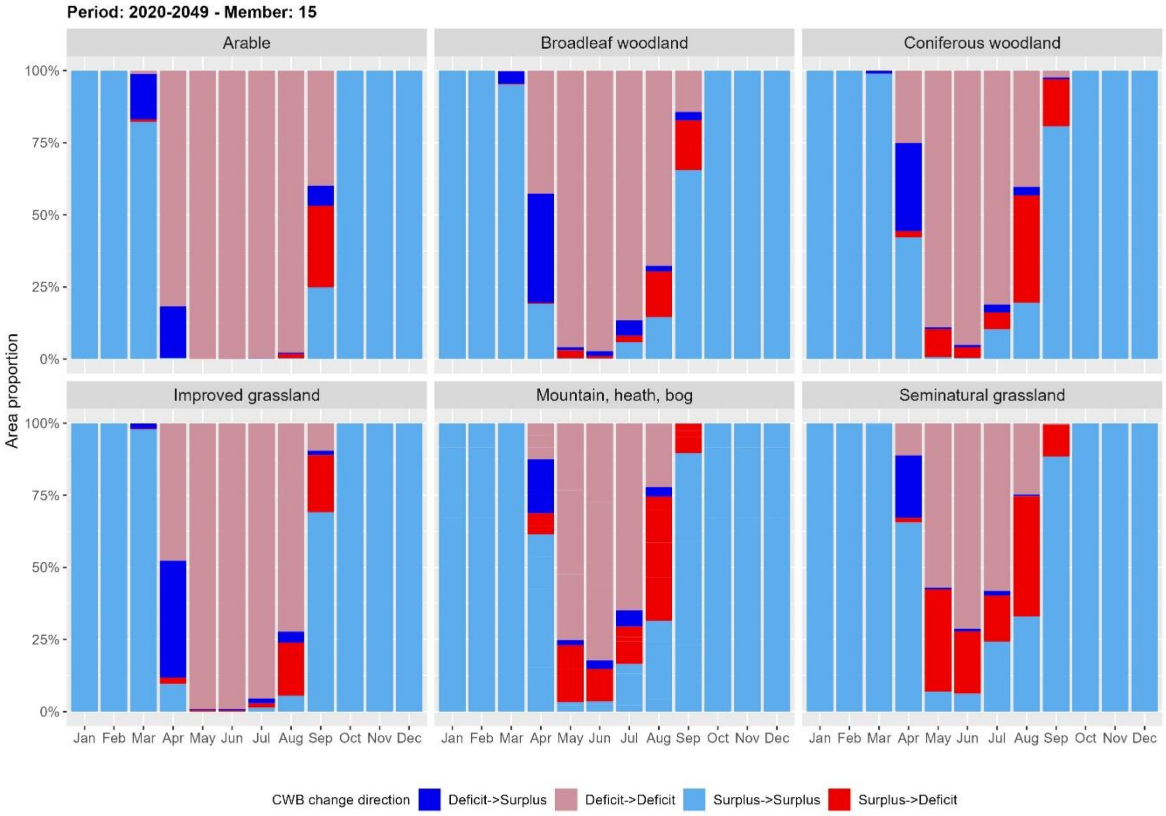

Figure A13. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2020 – 2049 period relative to the baseline period 1960-1989 using climate projections from EM15.

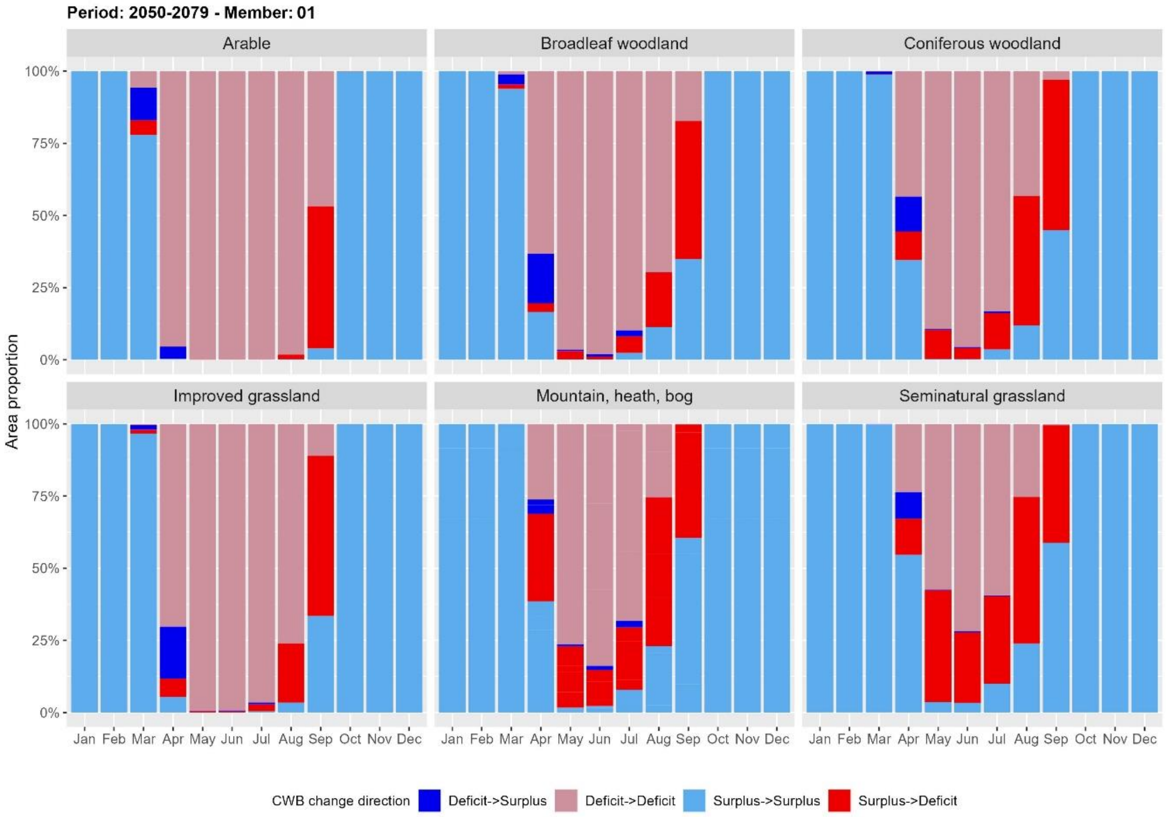

Figure A14. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM01.

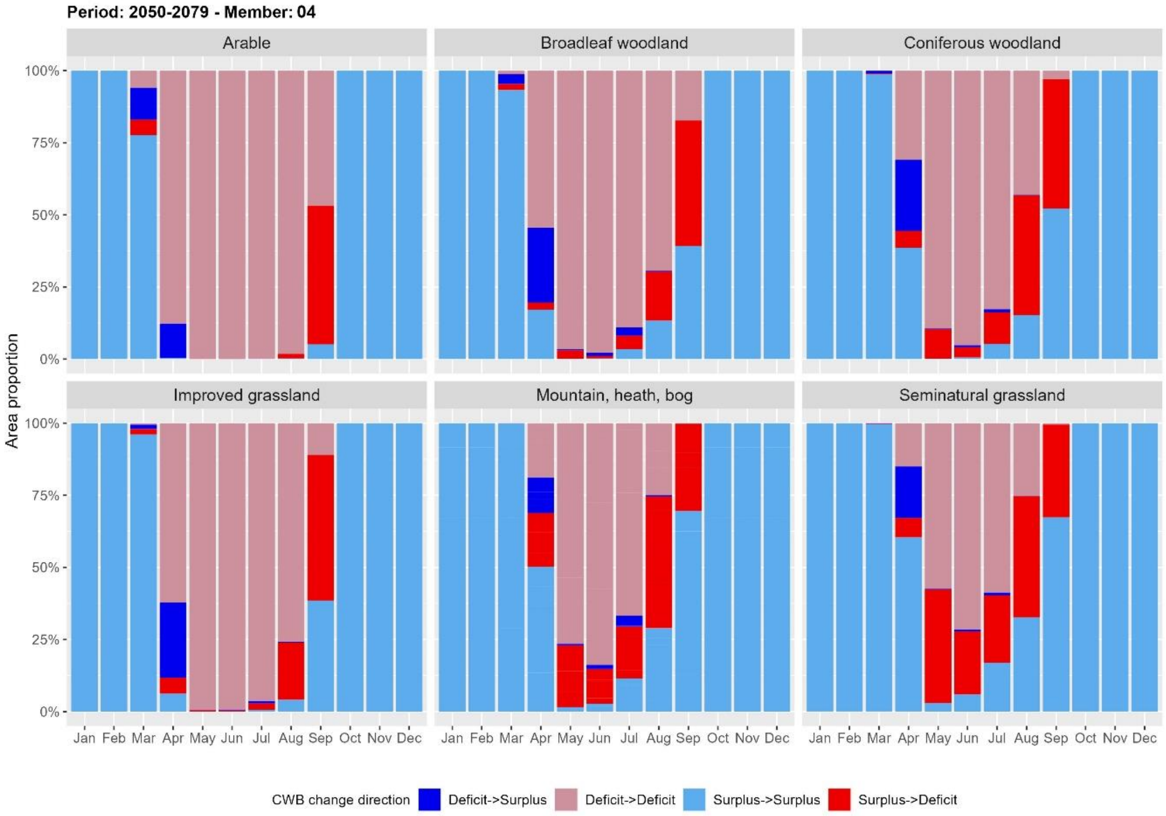

Figure A15. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM04.

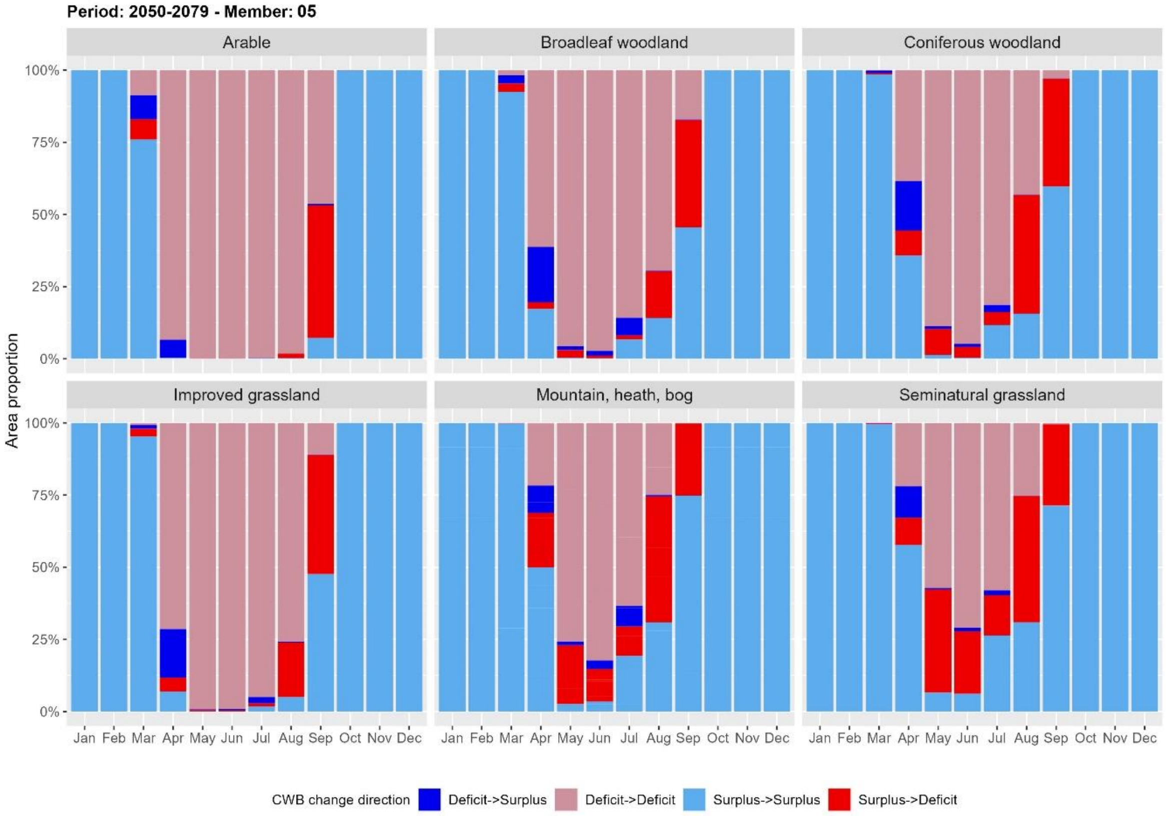

Figure A16. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM05.

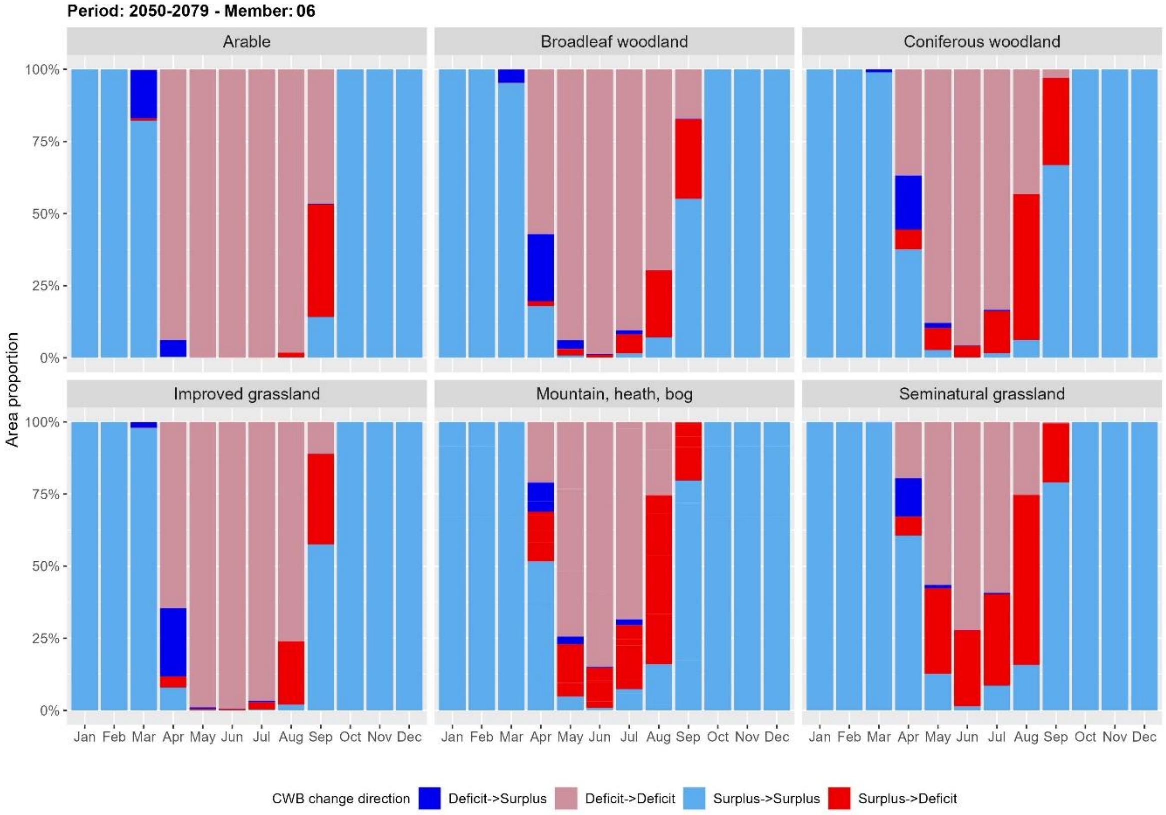

Figure A17. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM06.

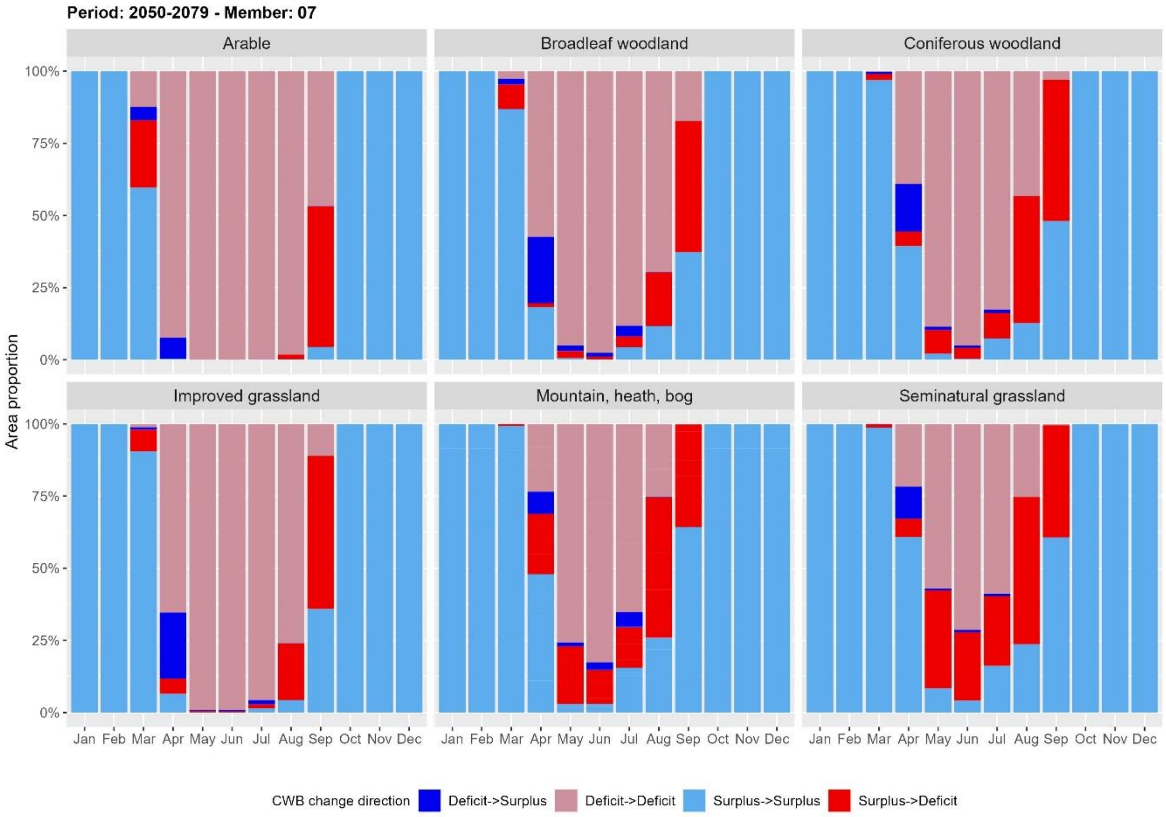

Figure A18. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM07.

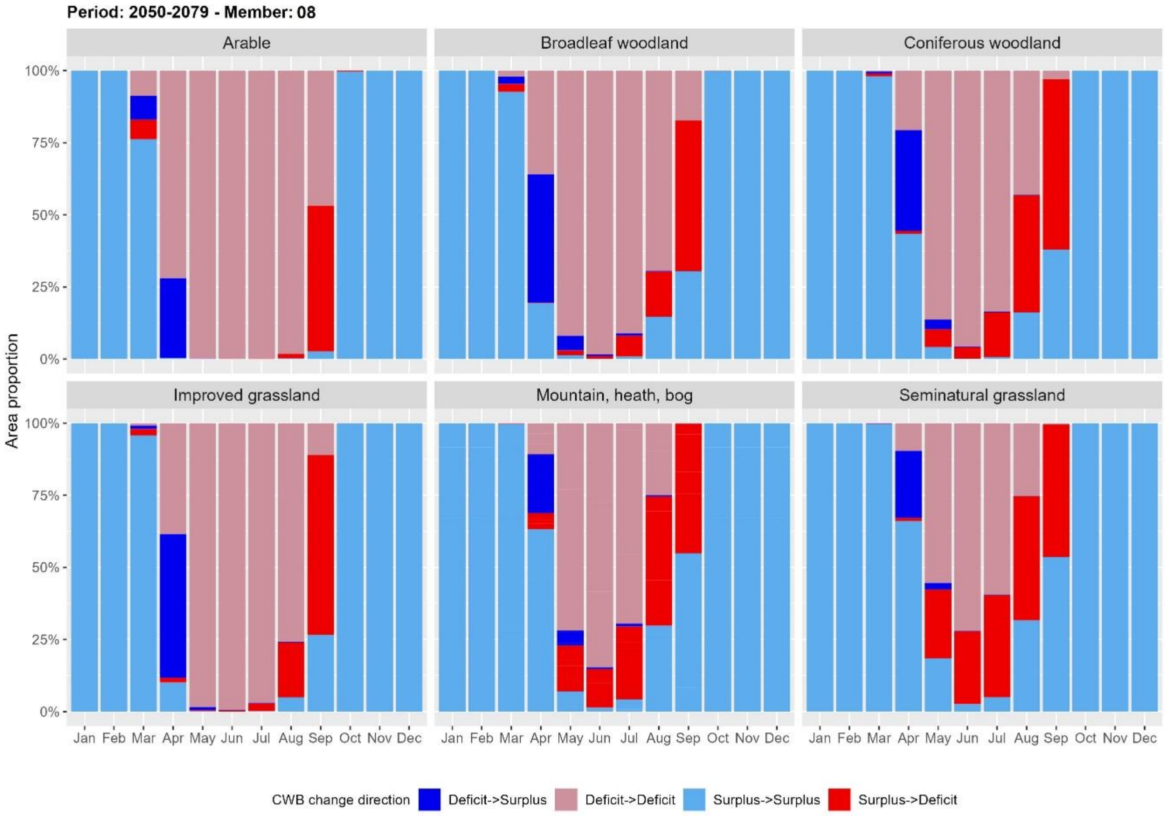

Figure A19. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM08.

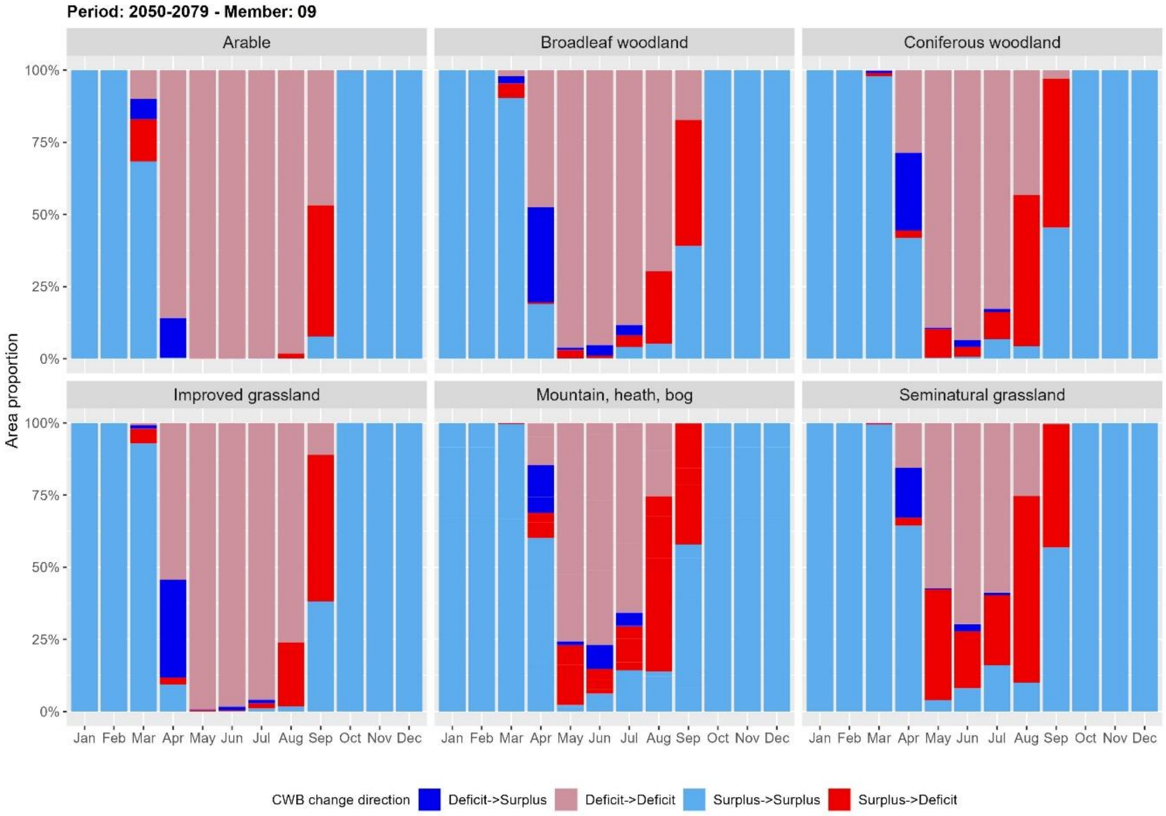

Figure A20. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM09.

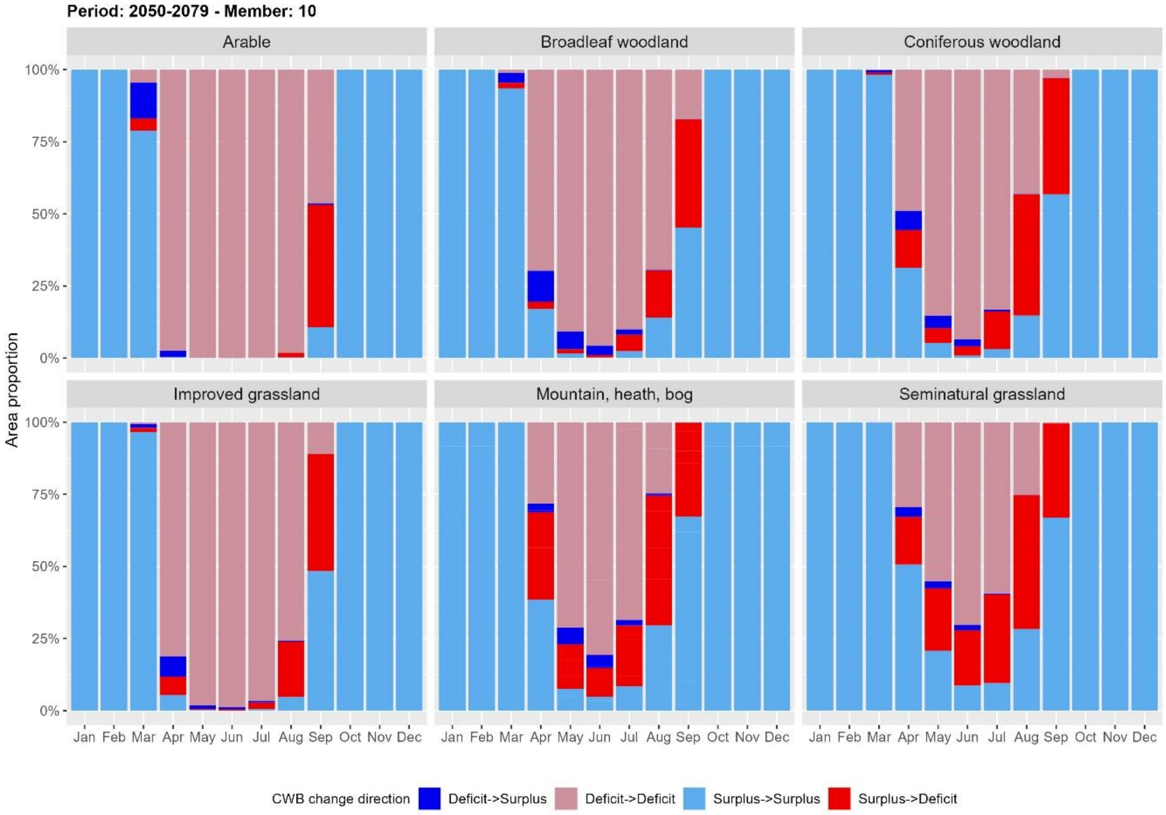

Figure A21. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM10.

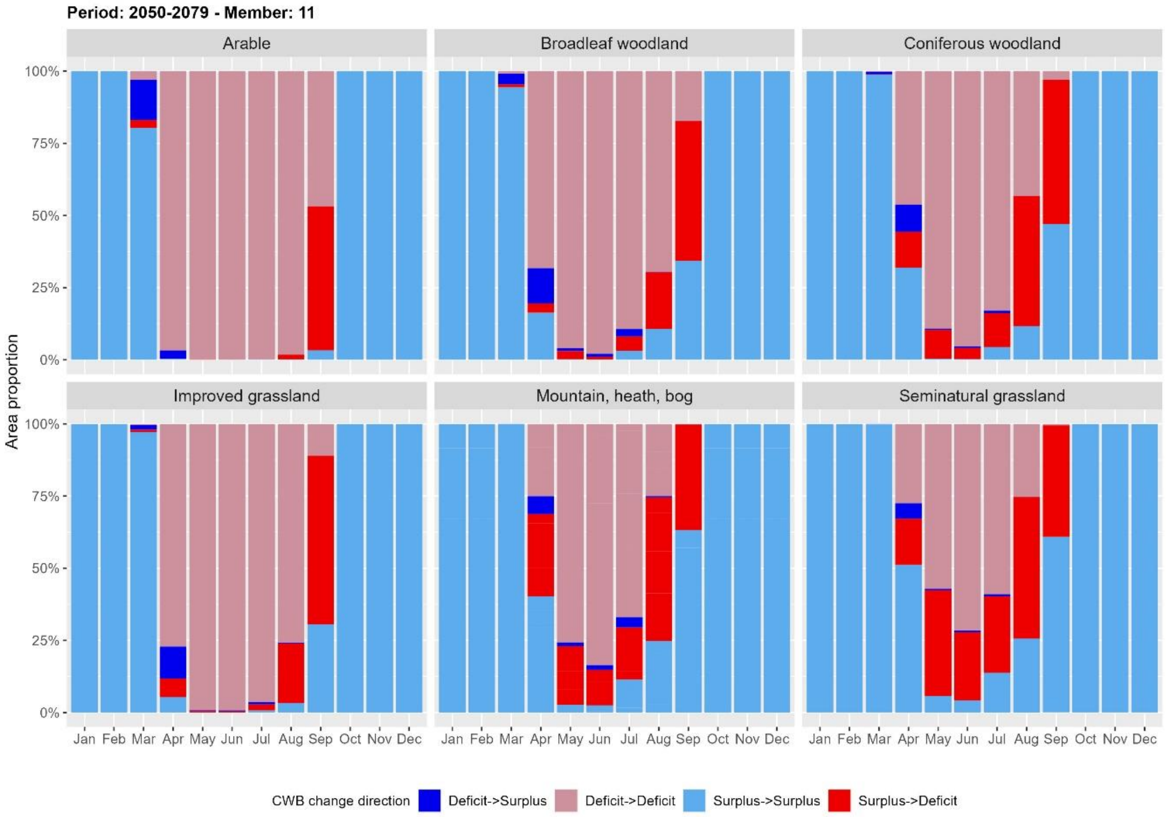

Figure A22. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM11.

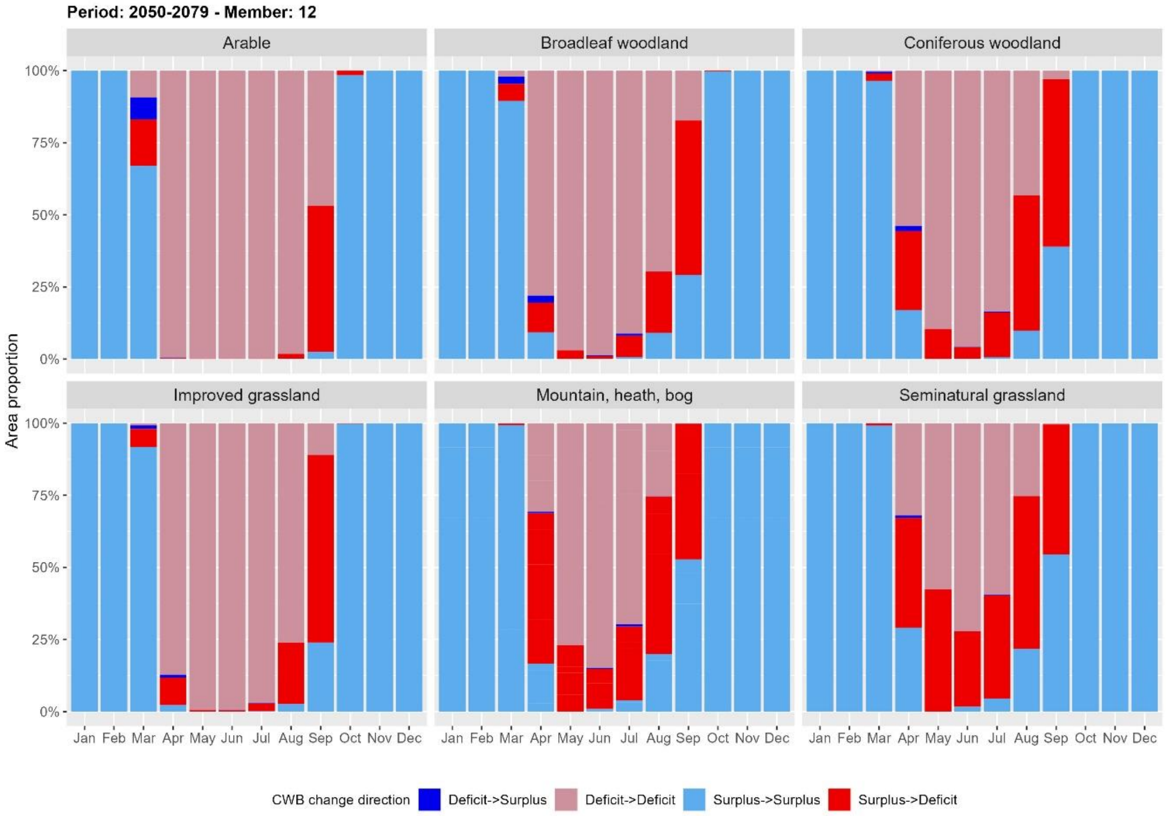

Figure A23. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM12.

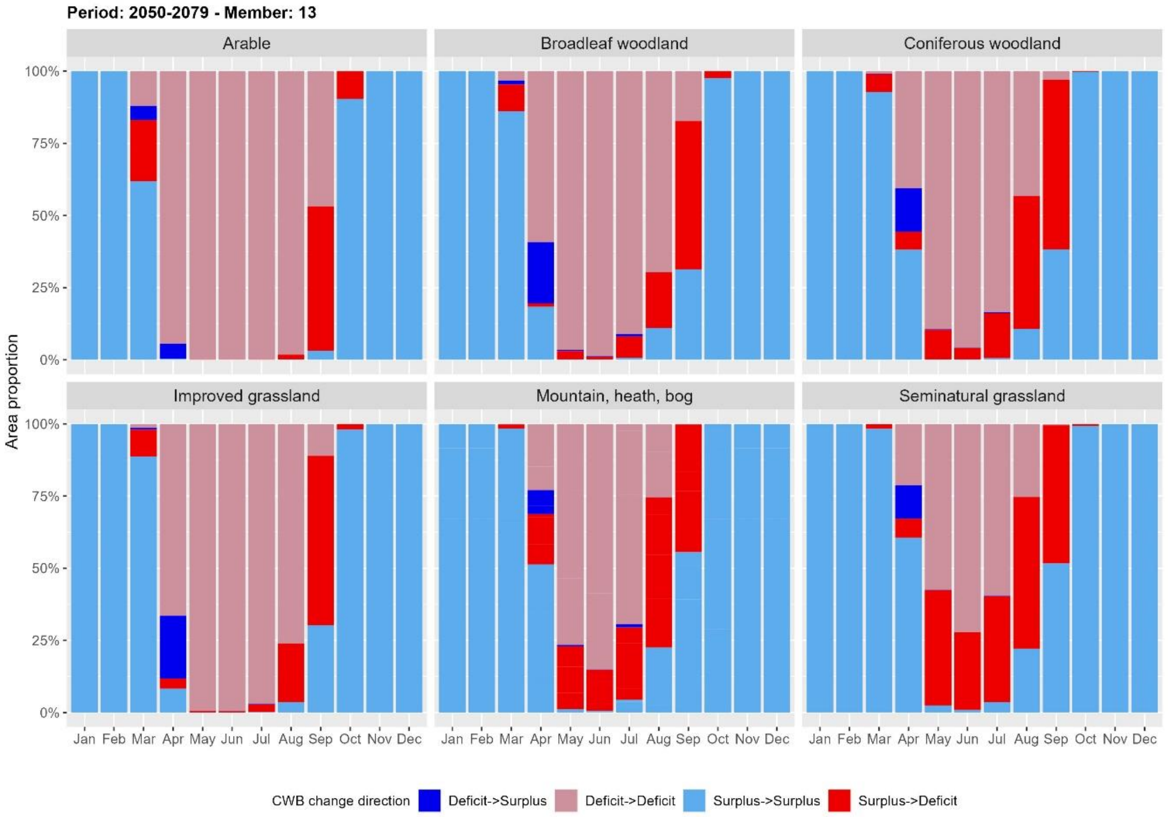

Figure A24. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM13.

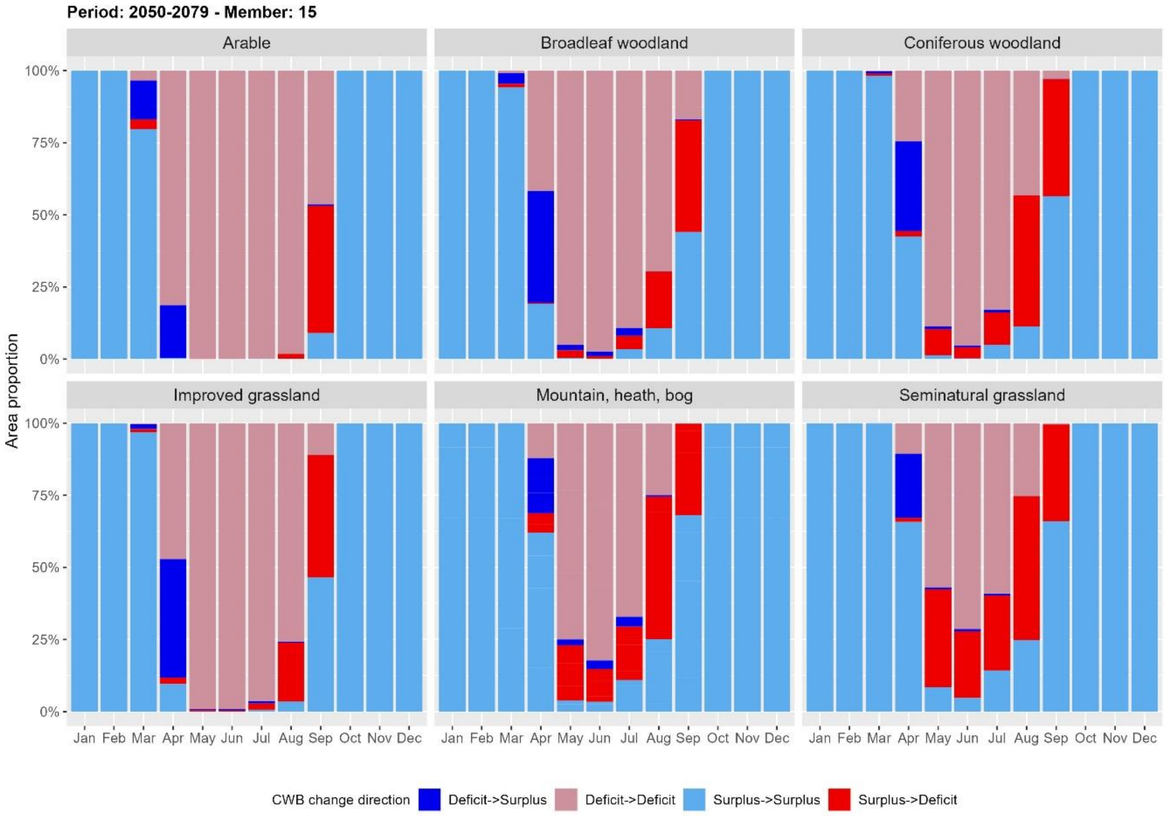

Figure A25. Area proportions for monthly change direction in CWB for Aggregated Cover for the 2050 – 2079 period relative to the baseline period 1960-1989 using climate projections from EM15.

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