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A Regulatory Mirage: Non-compliance with Regulatory Requirements in Australian Human-induced Regeneration Projects

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Abstract

The boom-and-bust nature of rangeland ecosystems makes them ill-suited to nature-based solution (NbS) carbon offset projects involving sequestration in vegetation and soils. The variability in these systems makes it difficult to determine whether observed stock changes are attributable to the project activities, creating additionality risks. The low and variable rainfall in rangelands also means stock increases will often be impermanent, being susceptible to reversals in droughts, a risk magnified by climate change. The vast areas and small potential for gains per unit area add further complications, making it difficult to accurately measure carbon stock changes at low cost. This creates pressure to trade accuracy for simplicity in measurement approaches, increasing the risk of measurement errors. Despite these risks, rangelands have been advanced as a location for offset projects because of low land costs and low opportunity cost, and a perception they are extensively degraded. The most prominent example globally is human-induced regeneration (HIR) projects under the Australian carbon credit unit (ACCU) scheme, which are purporting to regenerate permanent even-aged native forests (areas with ≥20% canopy cover from trees ≥2 metres high) across millions of hectares of largely uncleared rangelands, predominantly by reducing grazing pressure from livestock and feral animals. Existing research has shown limited forest regeneration in the credited areas of these projects and that most of the observed changes in tree cover are attributable to factors other than the project activities, most likely variable rainfall. Here we extend this research by evaluating compliance of a sample of 117 HIR projects with regulatory requirements. The results suggest most HIR projects are non-compliant with key regulatory requirements that are essential to project integrity. The findings point to major administrative and governance failings in Australia's carbon credit scheme.

1. Introduction

Rangelands are dynamic environments supporting extensive management systems, where impacts from people on ecosystems are entwined with complex natural drivers (Walker and Janssen, 2002). Over 50% of global land area is comprised of rangelands, incorporating diverse ecosystems (deserts, grasslands, shrub steppe, savannas, and open woodlands) primarily dominated by native grasses, forbs, shrubs, and scattered trees (Briske and Coppock 2023; Briske et al. 2024). Rangeland ecosystems have been advanced as an attractive location for nature-based solution (NbS) carbon offset projects through reforestation, afforestation and other forms of vegetation and land management (Bond et al., 2019, Parr et al., 2024; Vetter, 2020; Veldman et al., 2015), including in Australia (Garnaut 2008; 2011; CSIRO 2009; Cockfield et al. 2019; Fitch et al. 2022; Baynes et al. 2022; Bowen et al. 2022). The appeal of rangelands partly stems from a perception they are extensively degraded, with depleted carbon stocks in vegetation and soils. For advocates, there is an opportunity to replenish the stocks through carbon markets by incentivising changes in land use and land management. Reflecting the natural constraints in rangeland environments, the gains per unit area are generally small but the costs are low, due to the availability of cheap land and low opportunity costs (i.e. small forgone profit per unit land area from existing land management) (Garnaut 2008; 2011; CSIRO 2009; Cockfield et al. 2019; Fitch et al. 2022; Bowen et al. 2022). The concept is superficially enticing, offering a way of lowering the costs of mitigating greenhouse gas emissions, while restoring degraded ecosystems and improving the financial sustainability of pastoral enterprises and associated communities.

The difficulty for advocates of rangeland NbS carbon offset projects is that the defining features of rangelands – extensive areas with ‘boom-and-bust’ ecologies dictated by low and variable rainfall – creates integrity problems for carbon offsets (Gifford and McIvor 2009; Macintosh et al. 2024). The integrity of carbon offset projects depends on whether the credits issued to them represent real, additional and permanent abatement (Breidenich et al. 1998; Schneider and La Hoz Theuer 2019; Stubbs, M. et al. 2021; ERAC 2021). For rangeland NbS carbon offset projects, meeting these standards requires well-designed and administered rules that ensure issued credits represent genuine increases in carbon stocks (realness) that would not have occurred without the incentive provided by the scheme (additionality), and for the credited increases in carbon stocks to persist (permanence) (Gifford and McIvor 2009; Macintosh et al. 2024).

The characteristics of rangeland systems makes it hard to design and administer such rules. There are three problematic issues. Firstly, the natural variability of rangelands makes it difficult to determine whether, and the extent to which, any observed changes in carbon stocks in vegetation and soils are attributable to the project activities (Gifford and McIvor 2009; Carmody et al. 2022; Macintosh et al. 2024). That is, it is hard to determine whether increases in carbon stocks are additional. Secondly, the variability of rangeland systems means that, even where projects can generate additional increases in carbon stocks, the increases will often be impermanent, being susceptible to loss in droughts; a risk magnified in many areas by climate change (Gifford and McIvor 2009; Macintosh et al. 2024). Thirdly, the vast areas and small potential for gains make it difficult to accurately measure carbon stock changes at low cost, creating pressures to rely on simplified (and less accurate) measurement approaches (Victor 2009; Commonwealth of Australia 2014). Reliance on these simplified approaches increases the risk of measurement errors. These issues make it hard to manage the integrity risks with rangeland NbS carbon offset projects, rendering them inherently high risk because, where credits are issued that do not represent real, additional and permanent abatement, they generally facilitate net increases in greenhouse gas emissions.

The most prominent example globally of rangeland NbS carbon offset projects are those registered under the Australian carbon credit unit (ACCU) scheme's human-induced regeneration of even-aged native forests (HIR) method (Commonwealth of Australia, 2013; 2015a; 2016; 2018). HIR projects are meant to involve the regeneration of native forests on land that previously contained forest cover through changes in land management. While the method was originally intended for application to cleared lands (Department of the Environment 2014; Parliament of Australia 2013; Clean Energy Regulator 2014), most HIR projects are in rangeland areas that have never been comprehensively cleared of native vegetation (Macintosh et al. 2024). At the time of writing, there were 467 of these projects, covering 42 million hectares, with most claiming they are regenerating forests by reducing grazing pressure from livestock and feral animals (Clean Energy Regulator 2024). To date, these projects have received more than 43 million ACCUs (Clean Energy Regulator 2024), making them the largest pure removal carbon offset type, and the 5th largest NbS offset type, in the world by carbon credit issuances (Macintosh et al. 2024).

The HIR method and HIR projects have been highly controversial due to concerns the projects are unlikely to result in the regeneration of native forests in uncleared landscapes and that any observed increases in woody cover are more likely to be attributable to seasonal variability than the project activities (Long and McDonald 2022; Butler, D. et al. 2022; Carmody et al. 2022). However, a review published in early 2023, led by Australia's former Chief Scientist, Professor Ian Chubb (Chubb Review), concluded the "HIR method is sound - it meets the [offsets integrity standards] and is administered by a robust regulatory framework" (Chubb et al. 2022, at 21). Then in December 2023, the Regulator published a verification report (Brack report) on its administration of the HIR method that reached a similar conclusion:

> The independent audit reports and the [Regulator] reviews provide strong assurance that projects are being managed as per the legislative requirements and that appropriate methods have been used by the proponents or their agents in classifying the [carbon estimation areas] and identifying changes in regeneration canopy cover (Brack 2023, at 11).

Likewise, while not focused exclusively on HIR projects, a performance audit published by the Australian National Audit Office (ANAO) in April 2024 found the ACCU method development processes, and the administration of the issuing, compliance and contracting of ACCUs, were 'largely effective' (ANAO 2024, at 7).

The findings from these government reviews contrast sharply with peer reviewed research that analysed changes in woody cover within 182 HIR projects and found limited evidence of forest regeneration in credited areas (Macintosh, Butler *et al*. 2024). The research also found that changes in woody vegetation cover in the credited areas of the HIR projects largely mirrored changes in adjacent comparison areas, outside the projects, suggesting the observable changes were predominantly attributable to factors other than the project activities. These results raise questions about the extent of compliance with the requirements of the HIR method and the veracity of the findings from the government reviews concerning the robustness of the regulatory framework.

To further investigate this issue, we conducted an analysis of HIR projects to assess the likely extent of compliance with key regulatory requirements under the method. Compliance was evaluated using four regulatory tests derived from the HIR method and regulatory guidelines published by the Regulator (Commonwealth of Australia, 2013; 2015a; 2016; 2018; Clean Energy Regulator 2019). The project sample was confined to all projects registered between 2013 when the HIR method commenced and the end of 2016 with valid published credited area data (n=117). Compliance was assessed using three key datasets: the Woody Cover Fraction (WCF) dataset (Liao et al. 2020), which was used to assess compliance with canopy cover-based requirements; and the National Vegetation Information System and NSW State Vegetation Type dataset, both of which were used to assess compliance with cleared land requirements (Department of Climate Change, Energy, the Environment and Water 2023a; NSW Department of Climate Change, Energy, the Environment and Water 2023). The results suggest most HIR projects are non-compliant with key regulatory requirements that are essential to project integrity. The findings point to major administrative and governance failings in Australia's carbon credit scheme.

The remainder of the paper is set out as follows. Section 2 provides background context on the HIR method and its requirements. Section 3 details the method used to conduct the compliance analysis. Section 4 presents the results. Section 5 discusses the implications of the results and section 6 provides a conclusion.

2. HIR method requirements and background context

In contrast to other NbS initiatives in rangelands involving afforestation and reforestation (Briske et al. 2024), HIR projects do not involve tree planting or direct seeding. The HIR method requires forest regeneration to be induced from *in situ* seed and other sources through changes in land management, resulting in permanent even-aged native forests across the entirety of the areas that are credited ('credited areas').[1] Eligible project activities include

[1] Under the ACCU scheme, credited areas are formally known as 'carbon estimation areas'.

managing non-native plants and stopping clearing of native plant regrowth, but in practice the dominant project activity is reducing grazing pressure from livestock and feral animals.

Carbon sequestration in regeneration is not directly measured under the HIR method. Proponents of HIR projects are required to estimate sequestration using the Australian Government's Full Carbon Accounting Model (FullCAM) (or a simplified version of FullCAM called the Reforestation Modelling Tool (RMT)). FullCAM is a relatively simple mechanistic model that was designed for landscape-scale use to estimate emissions and removals associated with reforestation and deforestation in Australia's national greenhouse gas accounts (Richards and Evans 2004). The calibration used to model sequestration in HIR projects assumes credited areas start with little woody biomass and that regeneration progresses towards the maximum woody biomass potential under native vegetation across the entirety of the credited areas, following a sigmoidal growth curve with a prescribed age of maximum growth (Paul et al. 2015; Paul and Roxburgh 2020).

The use of this simple modelled approach to estimate sequestration was intended to promote uptake by lowering measurement costs for proponents. However, the trade-off was that it creates a material risk of over-crediting, where credited sequestration exceeds actual sequestration. To address this risk, seven requirements were included in the HIR method to ensure credited areas have the capacity to support forest regeneration and that the modelled outputs are likely to be conservative reflections of reality (Table 1).

Table 1. Regulatory requirements for HIR credited areas to minimise integrity risks, as derived from the HIR method (Commonwealth of Australia, 2013; 2015a; 2016; 2018)

No.	Regulatory requirement
R1	**Baseline forest cover rule**: Land included in the credited areas must not have had 'forest cover' (areas of at least 0.2 ha with woody vegetation ≥2m in height and ≥20% crown cover) at any time during the projects baseline period, defined as the 10-year period prior to the project commencement date or the date of the application for project registration.*
R2	**Forest potential rule**: Land included in the credited areas must have 'forest potential', defined as land ≥0.2 hectares with trees that, having regard to the location and characteristics of the land, are reasonably likely to reach ≥2 metres in height and provide crown cover of ≥20%.**
R3	**Suppression rule**: Regeneration on land included in the credited areas must have been prevented from achieving forest cover over the preceding 10-years (baseline period) by relevant 'suppressors' (clearing, grazing by livestock or feral animals, or weeds).
R4	**Project activity rule**: Credited areas must consist only of land on which the project activity is being undertaken, defined as inducing the establishment of a native forest from *in situ* seed, lignotubers or root stock (coppice) sources by undertaking one or more human-assisted regeneration activity.
R5	**Regeneration additionality rule**: Either regeneration must be a direct result of the project activities or, at the end of the baseline period, it must have been reasonable to expect it would be necessary to undertake one or more of the project activities on the land for it to attain forest cover.***
R6	**Even-aged regeneration rule**: Credited areas must consist only of land that first exhibited regeneration at or around the same time.
R7	**Consistent vegetation and management rule**: The regeneration must consist of a similar mix of native vegetation and be managed in a consistent manner

* There are four versions of the HIR method, made in 2013, 2015, 2016 and 2018 (Commonwealth of Australia, 2013; 2015a; 2016; 2018). The 2013 and 2015 versions of the method allowed project commencement dates to be backdated to 1 July 2007 and defined the baseline period as the 10-year period prior to project commencement. The 2016 and 2018 versions of the method did not allow project commencement dates to be backdated and defined the baseline period as the 10-year period prior to the date of the application for project registration.

** In the 2013 and 2015 versions of the method, forest potential was defined slightly differently as land ≥0.2 ha with trees that have the potential to reach ≥2 metres in height and provide crown cover of ≥20%. See s 1.3.

*** The 2013 version of the method requires the regeneration to be a direct result of the project activities (s 1.4(d)). The 2015 version of the method states that the method applies where 'there is regeneration which is a direct result' of the project activities (s 1.4(d)). The 2016 and 2018 versions state that it must be reasonable to expect it would be necessary to undertake one or more of the project activities on the land for it to attain forest cover (s 4(1)(c)).

These requirements, particularly the suppression (R3), project activity (R4), regeneration additionality (R5) and even-aged regeneration (R6) rules, were meant to ensure that only cleared lands that did not contain pre-existing mature trees were included in the credited areas of HIR projects (**R8: cleared land rule**), which reflect the assumptions underpinning the FullCAM HIR calibration. This is clear from the official legal guide to the interpretation of the original HIR method (known as the Explanatory Statement), which states:

> The Determination applies to projects in which land has been cleared of native vegetation and where regrowth has been suppressed for at least 10 years (Parliament of Australia 2013, at 1).

To eliminate doubt, the Explanatory Statement says the same thing in two other places, including in the section that governs the eligibility of land:

> The activity must occur on areas of cleared land on which regrowth has been regularly suppressed but has the potential to grow if suppression activities ceased, or on cleared areas that abut existing vegetation (Parliament of Australia 2013, at 7).

A review of the HIR method conducted by the Emissions Reduction Assurance Committee (ERAC) in 2017-2019 did not investigate the extent to which uncleared lands with pre-existing mature trees had been included in credited areas (ERAC 2019). However, the ERAC raised concerns about the absence of observed regeneration in credited areas and the risk of over-crediting due to the reliance on FullCAM (ERAC 2019). To address this, in late 2018, the Government introduced a new rule requiring 90% of credited areas to achieve forest cover within 15 years, assessed at 0.2-hectare scale (**R9: forest cover attainment rule**) (Commonwealth of Australia 2015b; Commonwealth of Australia 2015c).

The forest cover attainment rule was informed by an empirical relationship between tree and debris biomass in forest regeneration and crown cover in the forest systems where most HIR projects are located, which suggests forest cover should be achieved in stands of even-aged regeneration when biomass reaches 7.2 to 11 tonnes of dry matter per hectare (equivalent to 13.2–20.2 tCO_2 ha^{-1}) (Larmour et al. 2018). For most HIR projects, this level of sequestration is likely to be achieved after 10-14 years of unhindered modelled regeneration (ERAC 2019). Based on this, 15-years was chosen as a ‘generous’ cut-off point, when forest cover should have been achieved in most projects. However, the rule was preferentially applied to projects that were registered before the rule was initiated (Commonwealth of Australia 2015b; Commonwealth of Australia 2015c). For projects registered before 15 August 2018 (‘existing projects’), the 15-year timeline runs from the date the projects were registered (or the date the proponent modelled the commencement of regeneration if it is after the date of registration). For projects registered after this date, the timeline rules from the date they model the commencement of regeneration (‘new projects’).

In response to the introduction of the forest cover attainment rule, and concerns raised about the initial stratification of credited areas (ERAC 2019), in May 2019, the Regulator introduced new guidance on stratification and its interpretation of the method requirements (Clean Energy Regulator 2019) (Table 2).[2] The guidance requires credited areas to be broken into assessment cells of a prescribed size and for canopy cover to be assessed in each cell to ensure compliance with the initial stratification requirements and to ensure regeneration is progressing towards forest cover (known as the 'initial stratification and regeneration gateway check requirements'). Initial stratification gateway checks are conducted in years 1-5, followed by two regeneration gateway checks: the first in years 6-10 and the second in years 11-15. The requirements get progressively more stringent, and the cells get progressively smaller, as projects approach the forest cover assessment date. The logic behind the progressive tightening is that credited areas will be re-stratified at each gateway as necessary to remove non-compliant cells to ensure only areas that satisfy the forest cover attainment rule remain at the applicable 15-year cut-off point.

[2] In Australia's legal system, any guidance issued by government regulators on the interpretation of the law is not determinative and does not shape or constrain how courts interpret the law (Gageler 2015). Regulatory guidance documents merely provided direction on how the relevant regulator intends to interpret and apply the law.

Table 2. Initial stratification and regeneration gateway check requirements (adapted from Clean Energy Regulator 2019)

<table>
<tr><th>Initial stratification gateway</th></tr>
<tr><td>
Timing: Before submitting the first offset report due for submission after publication of the guidelines.
What: ‘Initial stratification must demonstrate, using the appropriate spatial scale that [credited areas] are on eligible land that does not contain pre-existing forest cover and only contains land with forest potential’.
Guideline requirements: Credited areas must:

exclude areas that had pre-existing forest cover at a scale of 0.2 or more hectares; and
only include areas with forest potential, defined as areas with either:

≥5% canopy cover of vegetation ≥ 2m height, assessed with cells at 200 to 1000-hectare scale, depending on the reporting year (see below); or
areas with sufficient trees and saplings on ground to achieve forest cover, based on sampling from plots.

Size of assessment cells:

Year 1: 1000ha, or total area of CEA if less than 1000ha
Year 2: 750ha, or total area of CEA if less than 750ha
Year 3: 500ha, or total area of CEA if less than 500ha
Year 4: 300ha, or total area of CEA if less than 300ha
Year 5: 200ha, or total area of CEA if less than 200ha

</td></tr>
<tr><th>First regeneration gateway</th></tr>
<tr><td>
Timing: Once between the 6th and 10th year of the project.
What: Credited areas must ‘be assessed and evidence must be demonstrated to show an increase in forest cover at the mapping scale appropriate to the relevant year. Remote sensing approaches must use the latest imagery sourced for the relevant year the report is submitted in or within the period being reported on'.
Guideline requirements: Credited areas covered in offsets reports submitted from the 6th to 10th project year must satisfy one of three tests:

≥7.5% canopy cover of vegetation over two metres in height at 100-hectare scale; or
5% increase in canopy cover of vegetation over two metres in height over five years; or
sufficient trees and saplings on ground to achieve forest cover.

</td></tr>
<tr><th>Second regeneration gateway</th></tr>
<tr><td>
Timing: Once every five years from the 10th year of the project.
What: Credited areas must ‘be assessed and evidence must be demonstrated to show an increase in forest cover at the mapping scale appropriate to the relevant year. Remote sensing approaches must use the latest imagery sourced for the relevant year the report is submitted in or within the period being reported on'.
Guideline requirements: Credited areas covered in offsets reports submitted from the 10th project year must satisfy one of two tests:

≥10% canopy cover of vegetation over two metres in height at 10-hectare scale; or
5% increase in canopy cover of vegetation over two metres in height over five years.

</td></tr>
</table>

Source: Clean Energy Regulator (2019).

3. Methods

3.1 Tests for regulatory compliance

Compliance with key requirements of the HIR method was evaluated by dividing the credited areas of sampled projects into 100 ha (1000m x 1000m) cells and then assessing each cell against four regulatory tests derived from the HIR method and the Regulator's initial stratification and regeneration gateway check requirements.

Cleared area test (T1): cells were deemed compliant if ≥80% of the credited area in the cell was assessed as having previously been comprehensively cleared. This test assesses compliance with the cleared land rule (R8), which is derived from the suppression (R3), project activity (R4), regeneration additionality (R5) and even-aged regeneration (R6) rules, and the statements in the Explanatory Statement to the HIR method that the 'activity must occur on areas of cleared land'. The 80% threshold for compliance was used to account for potential inaccuracies in the mapping of cleared areas.

Baseline forest test (T2): cells were deemed compliant if, in the credited area of the cells, the 3-year average canopy cover from woody vegetation ≥2 metres in height was <20% for all three-year periods from 2001-2003 until the date of project registration. This test assesses compliance with the baseline forest cover rule (R1), although with compliance assessed at the 100-ha rather than 0.2-ha scale. Ideally, the assessment period for each project would be confined to their baseline period. However, the information required to determine the baseline periods of projects are not published. As noted below Table 1, both the 2013 and 2015 versions of the HIR method allowed project commencement dates to be backdated to as early as 1 July 2007 and defined the baseline period as the 10-year period prior to project commencement. Data published by the Regulator suggests few (if any) projects have project commencement dates prior to 2010 (Clean Energy Regulator 2023; Macintosh et al. 2023). Using the period from 2001-2003 until the date of project registration ensures the compliance assessment period covers the full range of possible baseline periods for the projects.

First regeneration gateway test (T3-a and T3-b): cells were deemed compliant if, in the credited area of the cells, either:

(a) canopy cover from woody vegetation ≥2 metres in height in 2023 was ≥7.5% (T3-a); or

(b) canopy cover from woody vegetation ≥2 metres in height in 2023 was ≥5% more than:

   i. the lowest levels recorded between 2010 and the date of project registration for projects registered prior to 23 March 2016 (when backdating was allowed); or

   ii. the levels recorded in the year of project registration for projects registered on or after 23 March 2016 (T3-b).

This two-part test aligns with the first two limbs of the test used in the Regulator's first regeneration gateway check (Clean Energy Regulator 2019). The Regulator claims to use the regeneration checks to assess compliance with the forest potential rule (R2). The Regulator's initial stratification gateway check (Clean Energy Regulator 2019) also purports to assess forest potential, based on whether an assessed cell has ≥5% canopy cover of vegetation ≥2m height or the land included in the credited area has sufficient trees and saplings on ground to achieve forest cover. These tests were not used in the present study because:

- the requirement for cells to have ≥5% canopy cover from vegetation ≥2m height is inconsistent with the cleared land (R8), suppression (R3), project activity (R4), regeneration additionality (R5) and even-aged regeneration (R6) rules; and
- the direct sampling requirements are based on the premise that all seedlings and saplings that are present in an area at project commencement will grow to maturity, which ignores the effects of competition and seasonal variability on regeneration (Westoby, 1984).

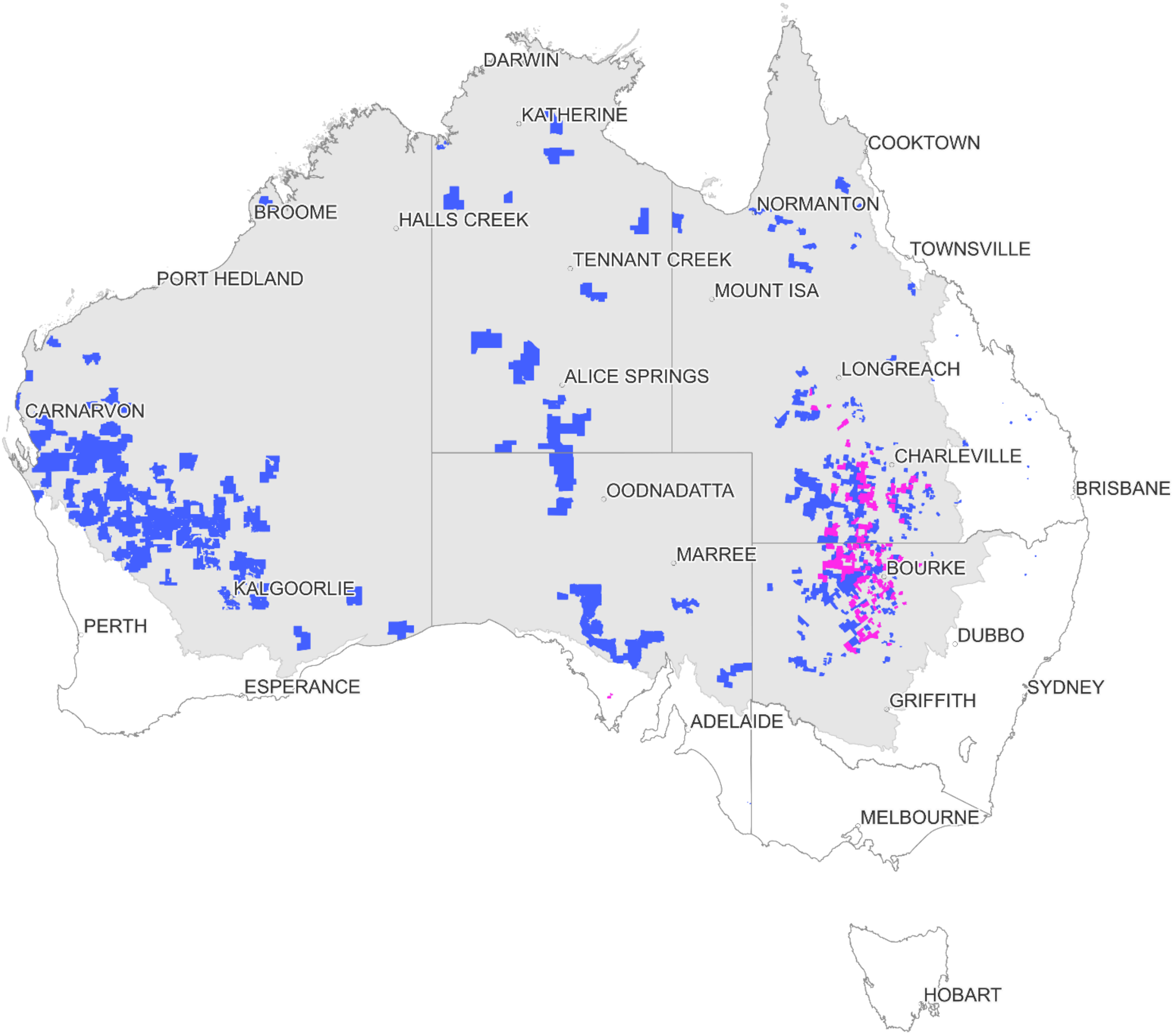
Additional cover test (T4): cells were deemed compliant if, in the credited area of the cells, average canopy cover from woody vegetation ≥2 metres in height over the period 2020-2023 was ≥5% more than the average canopy cover over the period of previous significant La Niña events in 1998-2001 or 2010-2012. This test provides a proxy measure of compliance with the forest potential (R2), suppression (R3), project activity (R4), and regeneration additionality (R5) rules, based on the premise that, if the credited areas satisfied these rules, average canopy cover over the period 2020-2023 should be significantly above the levels in

1998-2001 and 2010-2012. Significant La Niña events occurred in 1998-2001, 2010-2012 and 2020-2023, all three of which brought above average rainfall to the rangeland areas in New South Wales and Queensland where HIR projects are located (Huang et al. 2024; Bureau of Meteorology 2024). If the HIR projects were compliant with the method requirements, and operating as expected and in accordance with how they are credited, there should be a clear difference in detected canopy cover in the 2020-2023 La Niña event relative to the 1998-2001 and 2010-2012 events, which occurred before the HIR method was made.

3.2 Sample of HIR projects

As of 14 April 2024, there were 467 registered HIR projects (Clean Energy Regulator 2024). Credited area location data were available for 244 HIR projects, following changes to the law in April 2023 that allowed these data to be publicly available for the first time. The projects analysed were confined to those registered between 2013 when the HIR method commenced and the end of 2016 (n=130). Seven of these projects did not have published credited area, and the credited area data of a further six was corrupted, so these were excluded, leaving a total sample of 117 projects (Figure 1).

Figure 1. The extent of active HIR project areas (blue), with the subset of 117 projects analysed here (pink). Grey shading indicates the extent of rangelands defined by the Australian Collaborative Rangeland Information System.



Source: Department of Climate Change, Energy, the Environment and Water (2021).

The project sample was confined to projects registered prior to 2017 for two reasons. Firstly, under the Regulator's guidelines, proponents must demonstrate compliance with the initial stratification requirement check before submitting their first offsets report after the guidelines took effect and demonstrate compliance with the first regeneration gateway check in offsets reports submitted from year six until year 10 (Clean Energy Regulator 2019, at 21). Given the age of projects registered prior to 2017, it is reasonable to assume they have all been required to demonstrate compliance with both the initial stratification and first regeneration requirements by 2023 (the latest year in the WCF dataset). Secondly, most projects registered prior to April 2016 had backdated project commencement dates and regeneration modelling commencement dates (Clean Energy Regulator 2023; Macintosh et al. 2023). Consequently, confining the sample to projects registered prior to 2017 ensured the sample was confined to projects that, based on their credited sequestration, should have achieved significant forest regeneration (Larmour et al. 2018).

The majority of the projects in the sample were registered in 2015 (n=85), with only a handful registered in 2013 and 2014 (n=1 and n=3, respectively). Most projects are in western New South Wales (n=74), with the remainder in western Queensland (n=42) and a single project in South Australia: the first and only HIR project registered in 2013. The credited areas of the project in the sample cover 1.7 million ha, with 936,000 ha (55%) in New South Wales. Average credited area per project is larger in Queensland (18,000 ha ±11,700) versus New South Wales (12,700 ha ±14,600), with the South Australian project only 3,400 hectares.

Cleared land data and analysis

The proportion of the credited area in the cells that had previously been comprehensively cleared (T1) was estimated using one of two datasets. For projects located in Queensland and South Australia, we used a national 100m grid of major vegetation groups from the National Vegetation Information System (Department of Climate Change, Energy, the Environment and Water 2023). Grid cells assigned major vegetation group 25 (cleared) or 29 (regrowth) were deemed to be comprehensively cleared land. For projects in New South Wales, we used the NSW Statewide Vegetation Type data, generalised from a 5 m to a 100 m grid, where cells not classified as a native Plant Community Type, or classified as one of several native Plant Community Types derived by clearing, were deemed to be previously comprehensively cleared (NSW Department of Climate Change, Energy, the Environment and Water 2023a).

In these datasets, areas that have substantially regrown from previous clearing are generally not identified as previously cleared. Similarly, areas that have experienced more subtle forms of clearing such as selective fodder harvesting or thinning (Witt et al 2009; Witt 2013) are not generally classified as previously comprehensively cleared.

3.3 Woody vegetation cover dataset and analysis

Changes in canopy cover from woody vegetation in the credited areas were analysed using the woody cover fraction (WCF) dataset (Liao et al. 2020). WCF is a Landsat-derived product that represents the fraction of canopy above 2 m height, incorporating both woody and leaf canopy components. Cover and height estimates derived from airborne LiDAR and inventory-based biomass estimates were used to train a Random Forest algorithm to derive WCF, resulting a high accuracy for cover (estimation error of 0.07). Data resolution of WCF is 25-m across the Australian continent from 1988 onwards.

WCF was chosen for the analysis for three reasons. Firstly, WCF has a low estimation error and was calibrated and validated using a large dataset that includes data from sites in the regions containing HIR projects. Secondly, WCF was used in the 2023 verification report of the Regulator's administration of the HIR method for the purposes of assessing compliance with the initial stratification and gateway checks, demonstrating its acceptance by the Regulator and other relevant stakeholders as an appropriate remote sensing product for these purposes (Brack 2023). Thirdly, using the WCF for these purposes provides a way of cross-checking the results from Macintosh et al. (2024), as that study relied on the National Forest & Sparse Woody Database (Department of Climate Change, Energy, the Environment and Water 2023b).

3.4 Estimated credited sequestration

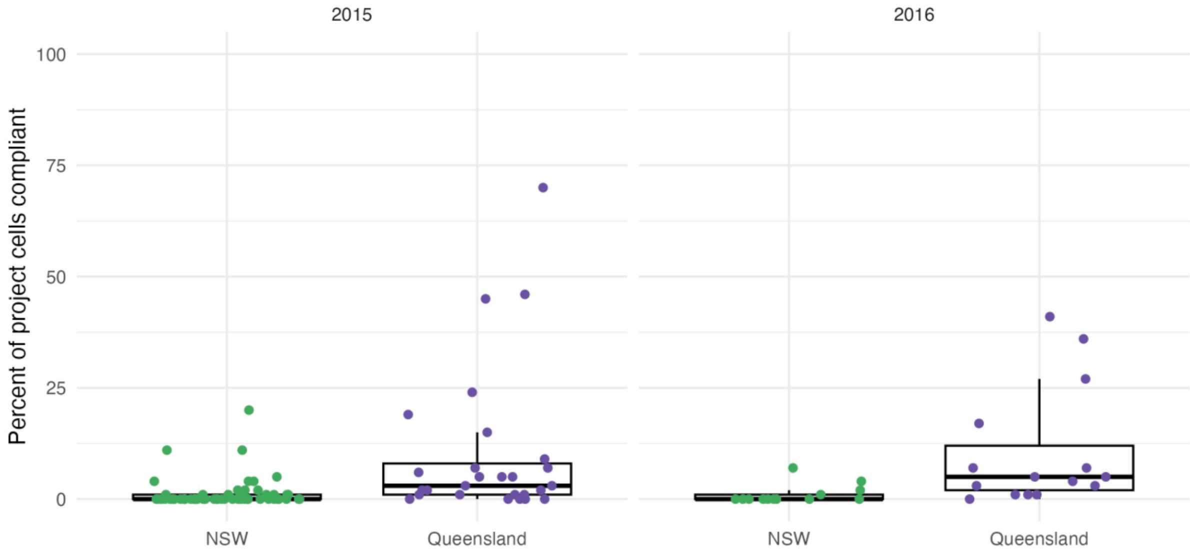
Following Macintosh et al. (2024), we estimated credited sequestration in our sample of HIR projects using data from the Emission Reduction Fund Project Register (Clean Energy Regulator 2024). Total credit issuances to each project to 30 June 2023 were adjusted to account for relevant discounts (5% risk of reversal buffer and a 20% permanence period discount for projects with 25 year permanence periods). We made a uniform and conservative 0.5% deduction to account for fossil fuel use, based on an Australian Government analysis (ERAC 2019). The resulting estimates were converted from CO_2 to C using the atomic mass ratio, 44/12.

4. Results

4.1 Cleared area test compliance (T1)

Of the 35,955 cells assessed across the 117 projects, only 1,698 (5%) satisfied the conditions of T1, being that ≥80% of the credited area in the cell was mapped as previously been comprehensively cleared (Tables S1 and S2). There were different rates of compliance depending on the date of project registration and the jurisdictions in which the projects are located (Figure 2). Projects registered in New South Wales had the highest rates of non-compliance (99% of cells were non-compliant), followed by those in Queensland (91%) and then the single project in South Australia (78%). All cells in projects registered in 2014 were non-compliant, and 95% of cells in projects registered in 2015 and 2016 were non-compliant (Table S2).

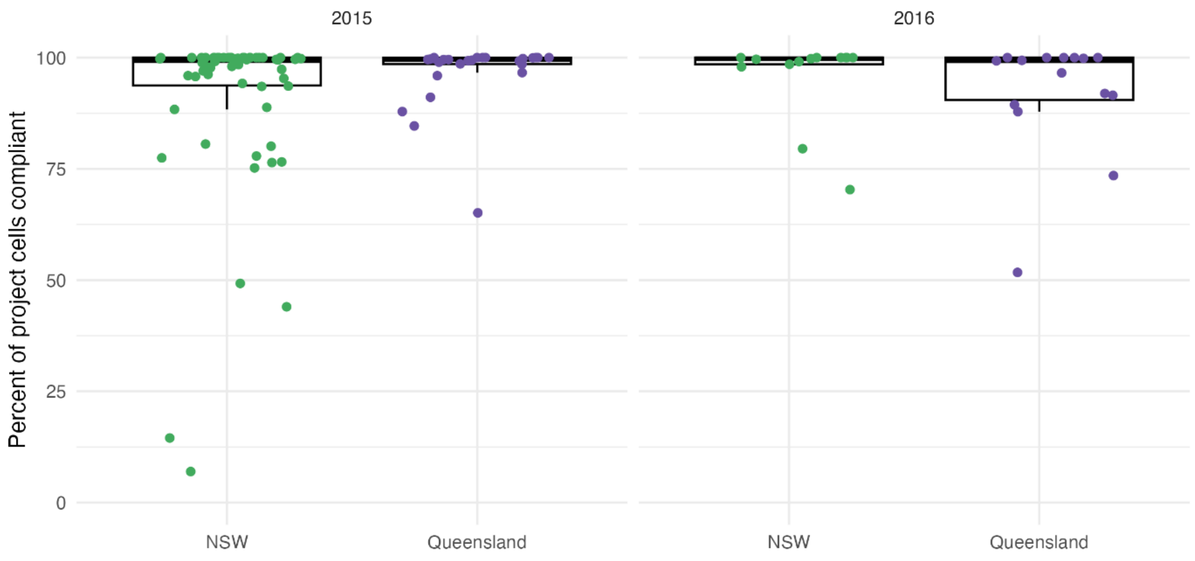
Figure 2. Percentage of cells within each project that were compliant with the cleared land rule compliance test (T1), 2015 and 2016 projects, by jurisdiction



4.2 Baseline forest test compliance (T2)

Most of the assessed cells satisfied the conditions of T2, which was used to assess compliance with the baseline forest cover rule. Of the 35,955 assessed cells, 34,131 (95%) were compliant (Tables S1 & S2). Compliance was lower in projects in New South Wales relative to those in Queensland, but rates of compliance did not differ significantly across the age cohorts of the projects (Figure 3). The South Australian project registered in 2013 was 100% compliant with T2. Notwithstanding the reasonable rates of compliance across the sample, a small proportion of projects had high to very high rates of non-compliance with T2. For example, ≥20% of cells were non-compliant with T2 in 14 projects, and more than 50% of cells were non-compliant with T2 in 4 projects (Figure S1).

Figure 3. Percentage of cells within each project that were compliant with the baseline forest cover rule compliance test (T2), 2015 and 2016 projects, by jurisdiction



4.3 First regeneration gateway test compliance (T3-a and T3-b)

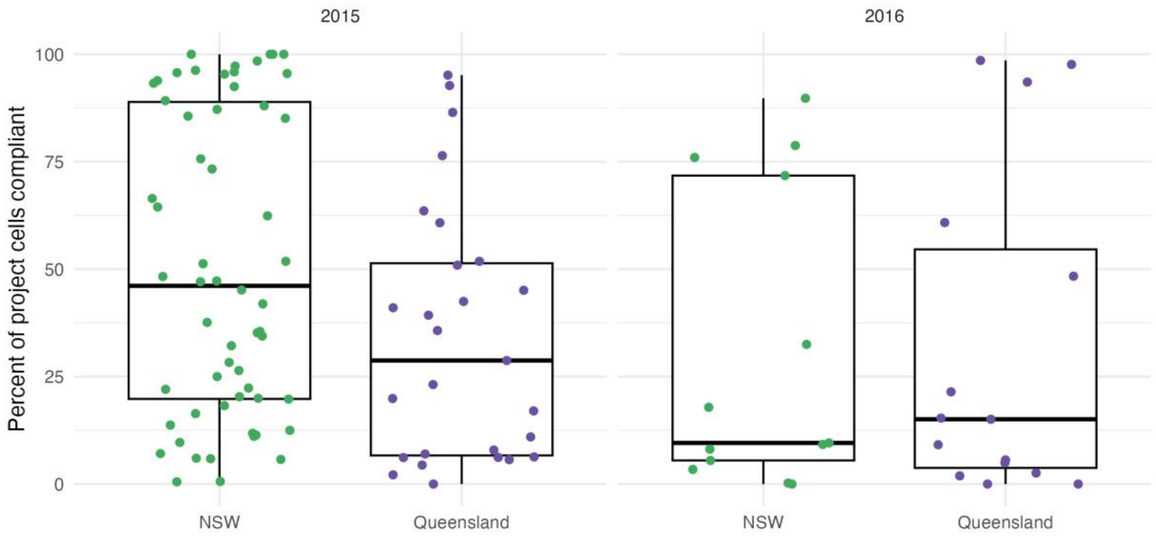
Cells were deemed compliant with the first regeneration gateway test if they satisfied either T3-a (canopy cover ≥7.5% in 2023) or T3-b (≥5% increase in canopy cover).

Of the 35,955 assessed cells, only 12,739 (35%) satisfied the conditions of T3-a, with the remaining 23,216 (65%) being non-compliant (Tables S3 & S4). The rates of non-compliance with T3-a were highest in South Australia (89%), then Queensland (76%), then New South Wales (55%). The rates of non-compliance with T3-a were generally higher in projects that were registered more recently: the proportion of non-compliant cells was 29% for 2014 projects, 63% for 2015 projects, and 70% for 2016 projects. 89% of the cells in the single 2013 project were non-compliant with T3-a.

Similar to the case with T3-a, only 10,458 (29%) of the assessed cells satisfied the conditions of T3-b, with the remaining 25,497 (71%) cells being non-compliant (Tables S3 & S4). These results suggest there have been only small increases in canopy cover across most cells. The rates of non-compliance were highest in South Australia (88%), then Queensland (76%), then New South Wales (67%). The rates of non-compliance with T3-b were the highest in the single 2013 project (88%) and projects registered in 2016 (80%). Forty-one per cent (41%) of the cells from the three projects registered in 2014 were non-compliant. Sixty-eight per cent (68%) of the cells from projects in 2015 did not comply with the cover change requirements of T3-b.

Consistent with the standalone results for T3-a and T3-b, there were high rates of non-compliance with the combined requirements of the first regeneration gateway check: 62% of assessed cells did not satisfy either T3-a or T3-b (Tables S2, Figure 4). The rate of non-compliance was highest in the single project in South Australia (88% of cells), followed by the Queensland projects (72% of cells). Fifty-four per cent (54%) of the cells in projects registered in New South Wales did not comply with the requirements of either T3-a or T3-b. In terms of the year of registration, non-compliance was highest in the single 2013 project (88%), then the projects registered in 2016 (69%) and 2015 (61%). The three projects registered in 2014 had the highest compliance rate, with 73% of cells compliant.

Figure 4. Percentage of cells within each project that were compliant with the first regeneration gateway check (T3-a or T3-b), 2015 and 2016 projects, by jurisdiction

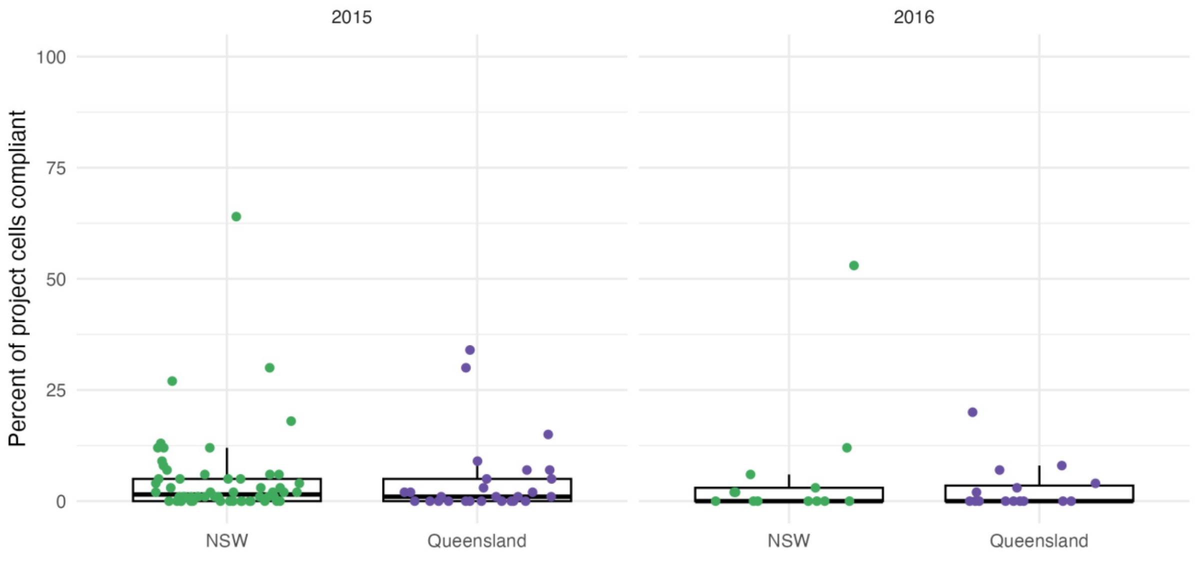


4.4 Additional cover test compliance (T4)

The additional cover test (T4) provides a proxy measure of the extent of compliance with the requirements of the forest potential, suppression, project activity and regeneration additionality rules (R2, R3, R3 and R4), measuring whether average canopy cover in assessment cells over the 2020-2023 La Niña event materially exceeded the levels recorded in the two previous comparable La Niña events (2010-2012) and (1998-2001), which occurred prior to the making of the HIR method in 2013.

Only 5% of the 35,955 assessed cells satisfied the requirements of T4 (Tables S1 & S2, Figure 5). The overwhelming majority of assessed cells (95%) were non-compliant, highlighting that the majority of credited areas in HIR projects had less woody cover in 2020-23 than in La Niña events prior to the commencement of HIR project activities. Non-compliance was reasonably consistent across the jurisdictions: 93% in cells from New South Wales projects; 97% in cells from Queensland projects; and 85% in cells from the single South Australian project. Non-compliance was lower in the four projects registered in 2013 and 2014 (85% and 79% of non-compliant cells respectively) than in 2015 and 2016 projects (95% and 96% respectively).

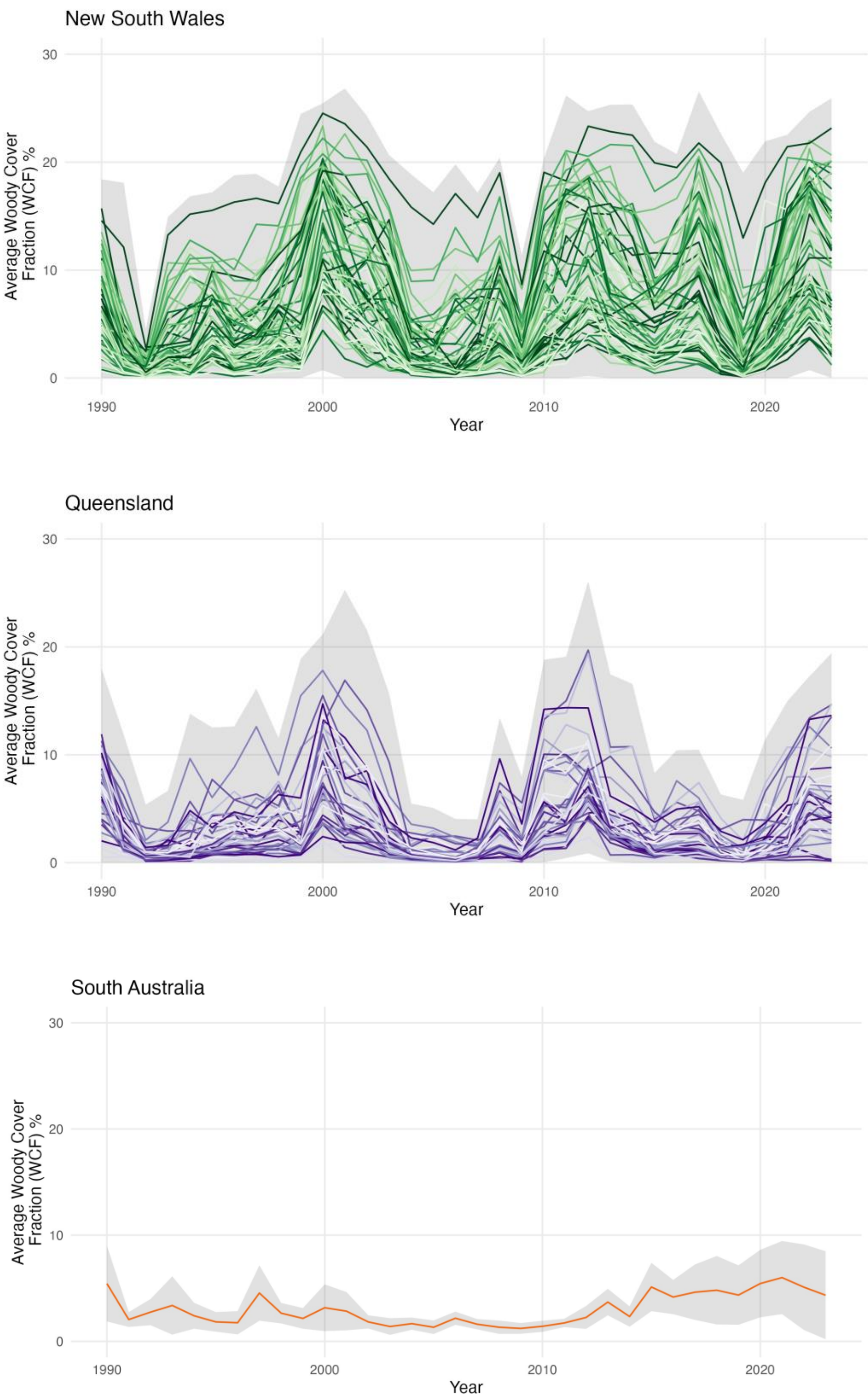
Figure 5. Percentage of cells within each project that were compliant with the additional cover test (T4), 2015 and 2016 projects, by jurisdiction



Two sensitivity scenarios were run on the results of T4, involving lower compliance thresholds. In the first, cells were deemed compliant if average canopy cover from woody vegetation over the period 2020-2023 was ≥2.5% above the average canopy cover over the period 1998-2001 or 2010-2012 (compared to ≥5%). In the second, the compliance threshold was lowered again to 0% (i.e. average canopy cover just needed to be above the averages in the 1998-2001 or 2010-2012 La Niña events). In the 2.5% sensitivity scenario, 83% of cells were non-compliant, 17% were compliant. In the 0% sensitivity scenario, 50% of cells were compliant, 50% were non-compliant.

Figure 6 shows the trends in mean canopy cover in the projects by jurisdiction and the standard error of the weighted means across the projects. Individual project trends are provided in the Supplementary Materials (Figure S2). The data show canopy cover in the credited areas largely fluctuating between 0% and 20%, with the peaks corresponding to wet periods (particularly the La Niña events in 1998-2001, 2010-2012, and 2020–2023) and the troughs corresponding to dry periods (particularly the El Niño events 1991-1992, 2002-2003, 2006-2007, 2015-2016, and 2017-2019). If the projects were compliant with the requirements of the method and performing in accordance to how they have been credited, canopy cover in each 100-ha cell within credited areas should have started near zero and increased to around 20% or more over the period 2010 to 2023. This has not occurred.

Figure 6. Average canopy cover in credited areas of projects, 1990 to 2023, by jurisdiction (grey shows standard error of weighted mean across the project cells)



4.5 Credited sequestration and canopy cover

The average credited sequestration of the full sample at 30 June 2023 was 22.0 tCO_2 ha^{-1} (median 17.2 tCO_2 ha^{-1}, sd 17.0 tCO_2 ha^{-1}). Eighty-seven of the projects (74%) had credited sequestration ≥13.2 tCO_2 ha^{-1} (mean 26.2 tCO_2 ha^{-1}, median 21.8 tCO_2 ha^{-1}, sd 17.9 tCO_2 ha^{-1}) (Clean Energy Regulator 2024). This suggests these 87 projects should have had near 100% forest cover across their credited areas at the time of the analysis (Larmour et al. 2018). Yet only four of the 87 projects had an average canopy cover in 2023 ≥20%. Similarly, only nine of the 87 projects had a maximum average canopy cover over the period 2020-2023 that was ≥20%. Mean maximum average canopy cover of the 87 projects over the period 2020-2023 was 10.8% (median 8.6%, sd 5.7%). No other projects in the full sample had an average maximum average canopy cover ≥20% over the period 2020-2023, and the mean maximum average canopy cover of all 117 projects over the period 2020-2023 was 9.7% (median 7.6%, sd 5.8%).

5. Discussion

Inappropriate targeting of rangeland ecosystems for forest-based nature-based solutions (NbS) is of global concern (Briske et al., 2024; Kumar et al., 2020; Parr et al., 2024; Veldman et al., 2015). Afforestation of naturally open ecosystems containing little or sparse woody vegetation can have detrimental consequences for biodiversity and for local communities who rely on the continued provision of ecosystem services (Fleischman et al., 2020; Vetter, 2020). Unlike the large-scale afforestation programs occurring in the rangelands of Africa, Asia and South America (Briske et al., 2024; Vetter, 2020), human-induced regeneration (HIR) projects under the Australian carbon credit unit (ACCU) scheme do not involve any direct tree planting. However, HIR projects still rely on the misconception that rangelands are degraded forests, with critical implications for biodiversity and the climate. The key risk for biodiversity under the current HIR regime is the significant missed opportunity to restore woodlands and forests that are routinely re-cleared for agriculture (Evans et al., 2015; Evans, 2016), which the inappropriate registration of HIR projects in uncleared rangelands effectively crowds out of the market. The use of carbon credits issued to NbS projects where actual abatement is not commensurate with credited abatement, and where carbon sequestration is unlikely to be real, additional, or permanent, leads to a net increase in carbon emissions.

Consistent with the findings from Macintosh, Butler, *et al.* (2024), our analysis here suggests that the HIR projects have had little influence on observed levels of woody vegetation cover. This is reflected in the results for the first regeneration gateway test (T3) and the additional cover test (T4). Almost two-thirds (62%) of the assessed cells failed the first generation gateway test (T3). In other words, 62% of the cells did not have ≥7.5% canopy cover in 2023 (T3-a) or experience a ≥5% increase in canopy cover between project commencement and 2023 (T3-b). Remarkably, despite 2023 coinciding with the last year of a rare three-year, triple-dip wet La Niña event, only 29% of assessed cells experience a ≥5% increase in canopy cover between project commencement and 2023.

The high rates of non-compliance with the first regeneration gateway test (T3) is made more significant by how low the bar is for compliant regeneration under the Regulator's guidelines (Clean Energy Regulator 2019). The first limb of the gateway check (T3-a) does not even require an increase in cover, with cells able to meet the test based solely on the canopy of pre-existing woody vegetation. The 5% or more increase in canopy cover required under the second limb of the check (T3-b) is also lenient, particularly given the age of the modelled regeneration in the projects in the sample. The way the T3-b test was implemented for the analysis made it even more generous because, for projects registered prior to 23 March 2016, it used the lowest levels of cover recorded between 2010 and the date of project registration.

The results for the additional cover test (T4) were worse than those for the first generation gateway test (T3): 95% of assessed cells did not satisfy the T4 test requirements. That is, average canopy cover in most of the assessed cells (95%) over the 2020-2023 La Niña was not materially above the levels recorded in the two previous comparable La Niña events (2010-2012) and (1998-2001). This result is made more noteworthy by the fact that most of the projects in the sample are likely to have been modelling even-aged forest regeneration for more than a decade to 2023, with some having modelled as much as 16 years of forest growth at the date of the assessment. This is reflected in the levels of credited sequestration but not supported by observable changes in woody cover fraction.

The biophysical explanation for the relative absence of observable regeneration in the projects is simple. Because the HIR projects are almost exclusively located in uncleared arid and semi-arid rangeland areas, their capacity to increase sequestration in these areas through natural regeneration of woody vegetation is likely to be limited (Richards and Brack 2004; Gifford and McIvor 2009; Sankaran et al. 2013). The areas are likely to be at or near their carrying capacity for woody vegetation, meaning any changes in tree cover are most likely to be attributable to seasonal variability in rainfall (Gifford and McIvor 2009; Eldridge and Sala 2023).

The only way HIR projects could regenerate forests in these areas is if grazing had previously significantly reduced tree cover. Grazing in Australia's uncleared rangelands has generally not had this effect. Vegetation structure in uncleared parts of Australia's eastern rangelands is broadly similar to that described by early explorers (Fensham 2008; Silcock et al. 2013). If anything, tree cover has tended to increase in grazed rangelands, at least since the mid twentieth century (Witt et al 2009; Witt 2013). The literature suggests grazing can have local, short-term negative effects on the recruitment and growth of trees and shrubs in rangelands (Brown 1985). However, over larger scales of space and time, it generally does not cause significant reductions in tree cover and its influence on woody plants is minimal compared to the effect of variable rainfall (Eldridge et al. 2011; Fensham et al 2011; Anadón et al. 2014; Archer et al. 2014; Lett et al. 2005). Due to this, it would be surprising if the projects were inducing significant regeneration. The data suggest they are not and, based on the available science, it seems inevitable that most HIR projects in uncleared areas will ultimately fail to meet the requirements of the forest cover attainment rule (R9). Moreover, recent analysis suggests that even if regeneration were succeeding rangeland HIR projects, much of the climate benefits would be reversed by albedo changes (Hasler et al. 2024).

Apart from the lack of regeneration, the results also suggest there are extreme levels of non-compliance in HIR projects with key regulatory requirements (Clean Energy Regulator 2019; Commonwealth of Australia, 2013; 2015a; 2016; 2018). Most (95%) of the 35,955 assessed 100 ha cells did not satisfy the requirements of the cleared land rule compliance test (T1), indicating widespread non-compliance with the cleared land rule (R8). The Regulator and the relevant Australian Government Department have recently claimed the HIR method does not require credited areas to be located on cleared lands (Clean Energy Regulator & Department of Climate Change, Energy, the Environment and Water, 2023). This claim is inconsistent with the provisions of the method and is directly contradicted by the Explanatory Statement, which, by law, is intended to assist in the interpretation of the method.[3] The claim the HIR method does not require lands included in credited areas to have been cleared also runs counter to materials published by the Regulator and Department in 2013 and 2014 (Department of the Environment 2014; Clean Energy Regulator 2014).

Almost 2/3rds of the assessed cells (62%) did not satisfy the requirements of the first regeneration gateway test (T3), which form part of the Regulator guidelines (Clean Energy Regulator 2019). This is despite the permissive nature of the tests (T3-a and T3-b) and the generous way they were applied in this analysis.

The levels of non-compliance with the additional cover test (T4) were almost identical to those from the cleared land rule compliance test (T1): 95% of assessed cells did not satisfy the test requirements. The compliance results on the additional cover test (T4) are hard to reconcile with the forest potential, suppression, project activity and regeneration additionality rules (R2, R3, R3 and R4).The only area where the analysis suggests compliance was reasonable was in relation to the baseline forest cover rule (T2). Most cells (95%) satisfied these requirements, although there are still a small number of projects with high to very high levels of non-compliance (≥20% of cells were non-compliant in 14 projects, and more than 50% of cells were non-compliant in four projects).

Overall, our results suggest the compliance regime for HIR projects has failed to uphold the integrity rules that are supposed to underpin the projects. As of 30 June 2023, the projects in the sample had received 24.9 million ACCUs. The credited sequestration in most of the projects (75%) has exceeded the point where the credited areas should have achieved forest cover. Yet average canopy cover across these projects over the 2020-2023 La Niña event was only 10.8%, and only 29% of assessed cells had experienced a ≥5% increase in canopy cover since project commencement. The results suggest the impacts of the projects on regeneration has been small. Canopy cover in the assessed cells has largely fluctuated between 0%-20%

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[3] Legislation Act 2003 (Cth), s 13; Acts Interpretation Act 1901 (Cth), s 15AB.

depending on seasonal conditions, with little evidence of even-aged forest regeneration, as is supposed to be occurring. The results are hard to reconcile with claims made by the Clean Energy Regulator and the Emissions Reduction Assurance Committee that there is no "persuasive evidence of a lack of integrity with the HIR method or any material problems with compliance" (Clean Energy Regulator 2022; ERAC, 2022).

Our findings here and in Macintosh, Butler *et al*. (2024) also contrast sharply with the conclusions of three recent Australian government commissioned reports, which all assert that there is a 'robust regulatory framework' governing the administration of HIR projects (Chubb, *et al.* 2022; Brack 2023; ANAO 2024). In relation to the Chubb Review and ANAO audit, the different conclusions are partly explained by the fact that neither of these reviews systematically analysed relevant data on the delineation of credited areas, regeneration within credited areas and compliance with regulatory requirements. Brack (2023) did quantitatively assess relevant data on regulatory compliance in HIR projects in an analysis that aimed to verify the robustness of the Regulator's processes for administering the initial stratification and regeneration gateway checks. To do this, Brack (2023) quantitatively assessed whether a sample of 25 projects met the initial stratification and regeneration gateway checks, using ~19 250m x 250m (6.25 hectare) cells within the credited areas of each the sampled projects. The report relied on the Australia's Environment Explorer (AEX) platform for these purposes, which uses WCF, only with the data presented at 250m x 250m scale (i.e. average canopy cover in the 250m x 250m cells derived from the underlying 25m x 25m WCF data).

Given that Brack (2023) relied on the same underlying dataset that was used in the present analysis, and that both Brack (2023) and this study evaluated compliance with the initial stratification and regeneration gateway check requirements, the results and conclusions should be similar, at least in relation to T2, T3-a and T3-b. For T2, they are. However, Brack (2023) suggests most of its sampled HIR projects satisfied the regeneration gateway check requirements, with 'the mean canopy area for [19 of the 26 sampled projects being] significantly greater than 7.5%' (Brack 2023, at 9). According to Brack (2023), '[o]verall, the [credited areas] appear to be regenerating well in the project areas, especially since 2020 and on average are significantly (p=0.05) above the 7.5% canopy cover threshold' (Brack 2023, p 9).

The difficulty with the Brack (2023) findings on the regeneration gateway checks is that its method does not reflect the applicable regulatory requirements. Neither the Regulator's gateway requirements nor the HIR method allow compliance to be assessed on the basis of averages drawn from the entire credited area (Clean Energy Regulator 2019; Commonwealth of Australia 2013; 2015a; 2016; 2018). Compliance must be assessed on a cell-by-cell basis at the prescribed scale. At the first regeneration gateway check, each 100-ha cell must be assessed against the applicable requirements. For projects relying on remote sensing data, these requirements are reflected in T3-a and T3-b. Brack (2023) did not assess compliance on cell-by-cell basis; it assessed compliance at the *project level* based on whether *average* canopy cover across its ~19 6.25 ha assessment cells was ≥7.5%. There are other peculiar aspects of the method used in Brack (2023), including the choice of 6.25 ha cells (rather than 100 ha) and the fact it assessed compliance based on maximum canopy cover levels over the period 2020-2022 rather than canopy cover in the most recent applicable dataset immediately prior to the submission of the relevant offset report, as required under the rules (Macintosh, Evans *et al*. 2024). It also does not quantitatively assess compliance in terms of cover increase, as per T3-b (Macintosh, Evans *et al*. 2024). However, most of the difference in the findings on compliance with the first regeneration gateway check between it and this study stems from Brack's (2023) use of project level averages drawn from across the ~19 6.25 ha cells. Most notably, the average maximum canopy cover over the period 2020-2022 in Brack (2023) was similar to the mean in this study from the period 2020-2023 (9.05% vs 9.66%), and the maximum canopy cover in most of the sample cells over the period 2020-2022 in Brack (2023) was ≤12.5%, well below where it should be based on the levels of credited sequestration.

6. Conclusions

US legal scholar Dan Farber once wrote that, '[i]n all areas of law, there are gaps between the "law on the books" and the "law in action", but in environmental law the gap is sometimes a chasm' (Farber 1999, at 297). The results of the analysis suggest HIR projects are such a case, where there is a yawning gulf between the legal requirements of the method (the 'law on the books') and how projects are being regulated in practice (the 'law in action').

Carbon offsets are a high-risk policy instrument, both because of the difficulty in ensuring credits represent real, additional and permanent abatement and the fact that, when they do not, offsets tend to increase greenhouse gas emissions. The high-risk nature of offsets means they should be used with caution. Robust scheme rules are needed to ensure offset projects are only allowed to be undertaken when integrity risks can be adequately managed. Scheme rules should also mandate conservative estimates of abatement and put in place appropriate measures to mitigate permanence risks. However, well-designed scheme rules are of little use without robust compliance and enforcement.

In the context of debates about the integrity of HIR projects and the robustness of the regulatory framework governing them, this study quantitatively assessed the likely extent of compliance with key regulatory requirements under the HIR method. Compliance was evaluated using four regulatory tests derived from the HIR method and regulatory guidelines published by the Regulator. The credited areas of 117 HIR projects were divided into 35,955 100-ha cells and each cell was then evaluated against the four regulatory tests using the WCF dataset, which was relied on in a verification report published by the Regulator in 2023 (Brack, 2023).

These findings are of global significance, raising questions about the role offsets can play in global decarbonisation efforts. Offsets theoretically provide a means of lowering the cost of mitigating greenhouse gas emissions while enabling hard-to-abate sectors to contribute decarbonisation while technical solutions to abate onsite emissions are progressed. The prominence of offsets is reflected in international legal and policy structures, including the Paris Agreement's Article 6.4 Mechanism and the Carbon Offsetting and Reduction Scheme for International Aviation. There is already a large and growing body of evidence suggesting offset schemes are frequently plagued by integrity issues (Schneider & Kollmuss 2015; Badgley et al. 2022; Stapp et al., 2023; Cames et al. 2016; West et al. 2020; 2023; 2024). The focus on compliance failures in this study adds to a new dimension to the literature, showing how integrity problems can arise from the maladministration of methods and associated breakdowns in governance processes.

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Conflicts of Interest:

Andrew Macintosh is a non-executive director of Paraway Pastoral Company Ltd. Paraway Pastoral Company Ltd has offset projects under Australia's offset scheme. Paraway Pastoral Company Ltd does not have any human-induced regeneration projects.

Andrew Macintosh, Don Butler, Dean Ansell and Marie Waschka advise public and private entities on environmental markets and Australia’s carbon offset scheme, including on the design of carbon offset methods.

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Data Availability Statement

The data that support this study will be shared upon reasonable request to the corresponding author.

Supplementary Materials

Table S1. Number of cells that were compliant and non-compliant with T1, T2, T3-a or T3-b, and T4, by jurisdiction

Jurisdiction		Projects	Cells	Compliant	Non-compliant
Cleared land rule compliance test (T1)					
New South Wales	no.	74	19765	221	19544
	%			1%	99%
Queensland	no.	42	16118	1461	14657
	%			9%	91%
South Australia	no.	1	72	16	56
	%			22%	78%
Total	no.	117	35955	1698	34257
	%			5%	95%
Baseline forest test (T2)					
New South Wales	no.	74	19765	18177	1588
	%			92%	8%
Queensland	no.	42	16118	15882	236
	%			99%	1%
South Australia	no.	1	72	72	0
	%			100%	0%
Total	no.	117	35955	34131	1824
	%			95%	5%
First regeneration gateway check (T3-a or T3-b)					
New South Wales	no.	74	19765	9102	10663
	%			46%	54%
Queensland	no.	42	16118	4435	11683
	%			28%	72%
South Australia	no.	1	72	9	63
	%			13%	88%
Total	no.	117	35955	13546	22409
	%			38%	62%
Additional cover test (T4)					
New South Wales	no.	74	19765	1386	18379
	%			7%	93%
Queensland	no.	42	16118	529	15589
	%			3%	97%
South Australia	no.	1	72	11	61
	%			15%	85%
Total	no.	117	35955	1926	34029
	%			5%	95%

Table S2. Number of cells that were compliant and non-compliant with T1, T2, T3-a or T3-b, and T4, by year of project registration

Year of registration		Projects	Cells	Compliant	Non-compliant
Cleared land rule compliance test (T1)					
2013	no.	1	72	16	56
	%			22%	78%
2014	no.	3	1127	1	1126
	%			0%	100%
2015	no.	85	23626	1097	22529
	%			5%	95%
2016	no.	28	11130	584	10546
	%			5%	95%
Total	no.	117	35955	1698	34257
	%			5%	95%
Baseline forest test (T2)					
2013	no.	1	72	72	0
	%			100%	0%
2014	no.	3	1127	1100	27
	%			98%	2%
2015	no.	85	23626	22257	1369
	%			94%	6%
2016	no.	28	11130	10702	428
	%			96%	4%
Total	no.	117	35955	34131	1824
	%			95%	5%
First regeneration gateway check (T3-a or T3-b)					
2013	no.	1	72	9	63
	%			13%	88%
2014	no.	3	1127	821	306
	%			73%	27%
2015	no.	85	23626	9263	14363
	%			39%	61%
2016	no.	28	11130	3453	7677
	%			31%	69%
Total	no.	117	35955	13546	22409
	%			38%	62%
Additional cover test (T4)					
2013	no.	1	72	11	61
	%			15%	85%
2014	no.	3	1127	241	886
	%			21%	79%
2015	no.	85	23626	1229	22397
	%			5%	95%
2016	no.	28	11130	445	10685
	%			4%	96%
Total	no.	117	35955	1926	34029
	%			5%	95%

Table S3 Number of cells that were compliant and non-compliant with the first and second limb of the first regeneration gateway check (T3-a & T3-b), by jurisdiction

Jurisdiction		Projects	Cells	Compliant	Non-compliant
1st limb of first regeneration gateway check (T3-a)					
New South Wales	no.	74	19765	8842	10923
	%			45%	55%
Queensland	no.	42	16118	3889	12229
	%			24%	76%
South Australia	no.	1	72	8	64
	%			11%	89%
Total	no.	117	35955	12739	23216
	%			35%	65%
2nd limb of first regeneration gateway check (T3-b)					
New South Wales	no.	74	19765	6584	13181
	%			33%	67%
Queensland	no.	42	16118	3865	12253
	%			24%	76%
South Australia	no.	1	72	9	63
	%			13%	88%
Total	no.	117	35955	10458	25497
	%			29%	71%

Table S4 Number of cells that were compliant and non-compliant with the first and second limb of the first regeneration gateway check (T3-a & T3-b), by year of project registration

Year of registration		Projects	Cells	Compliant	Non-compliant
1st limb of first regeneration gateway check (T3-a)					
2013	no.	1	72	8	64
	%			11%	89%
2014	no.	3	1127	803	324
	%			71%	29%
2015	no.	85	23626	8642	14984
	%			37%	63%
2016	no.	28	11130	3286	7844
	%			30%	70%
Total	no.	117	35955	12739	23216
	%			35%	65%
2nd limb of first regeneration gateway check (T3-b)					
2013	no.	1	72	9	63
	%			13%	88%
2014	no.	3	1127	664	463
	%			59%	41%
2015	no.	85	23626	7584	16042
	%			32%	68%
2016	no.	28	11130	2201	8929
	%			20%	80%
Total	no.	117	35955	10458	25497
	%			29%	71%

Figure S1. Proportion of cells that were compliant with the baseline forest test (T2), by project

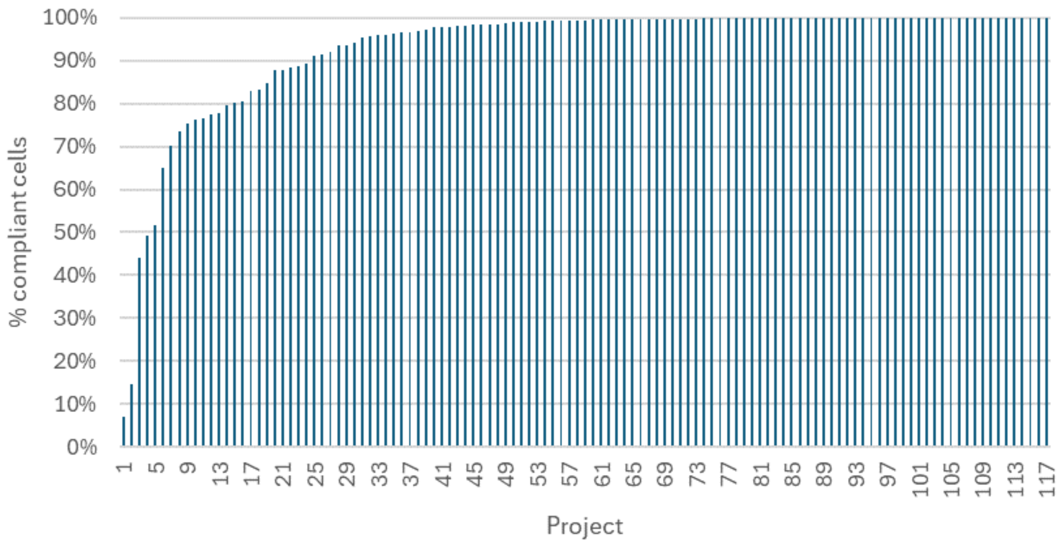
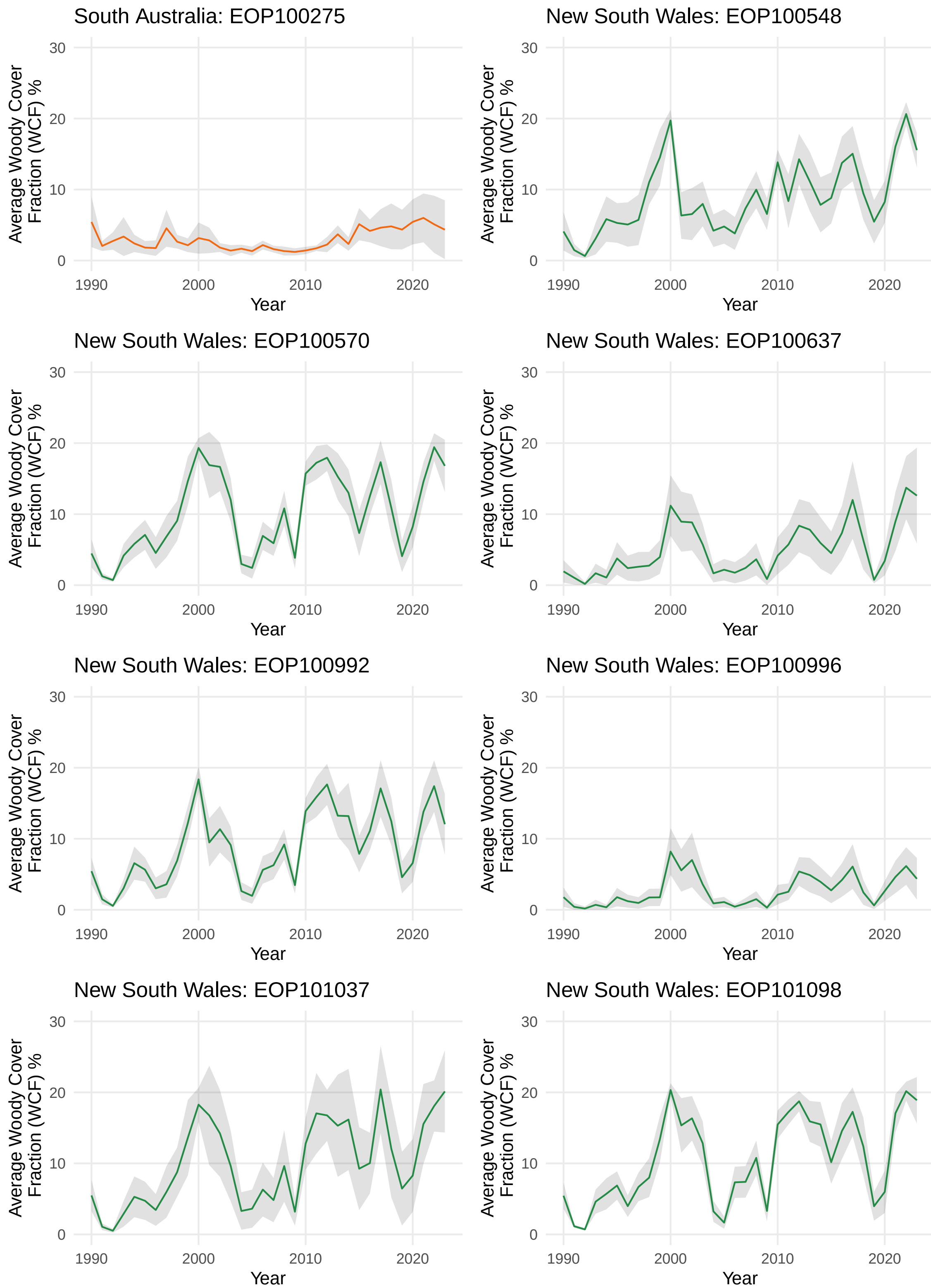


Figure S2. Average canopy cover in credited areas of projects, 1990 to 2023, by Project ID in the Emissions Reduction Fund Register (Clean Energy Regulator, 2024). Grey shows standard error of weighted mean across the project cells.



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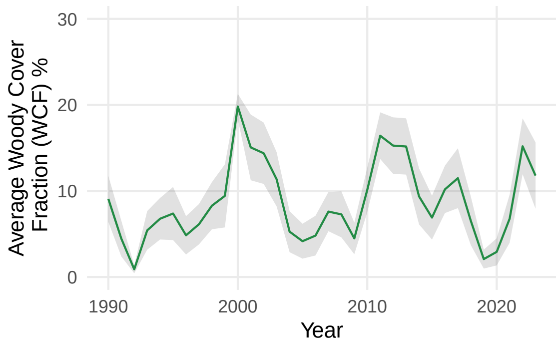

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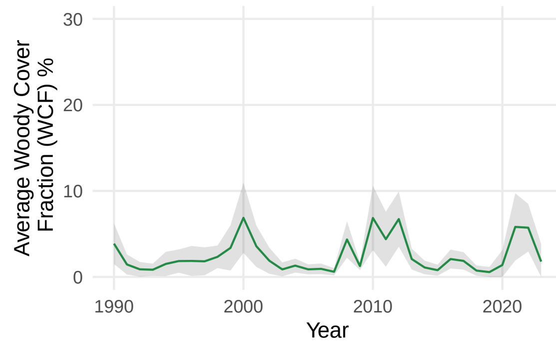

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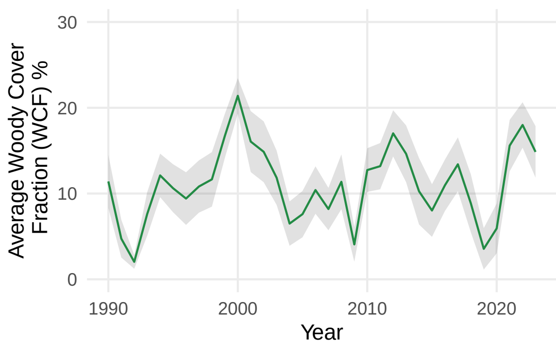

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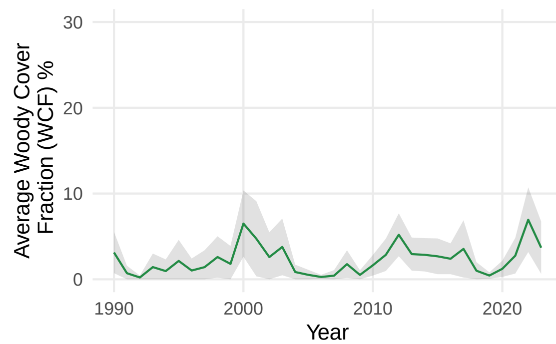

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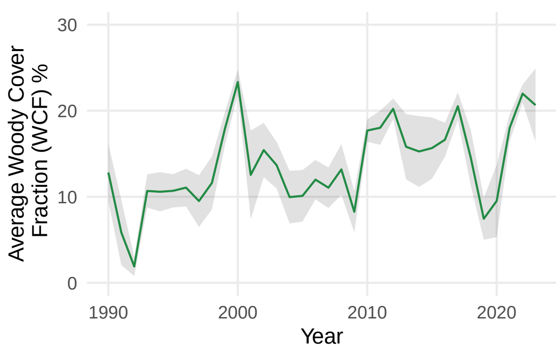

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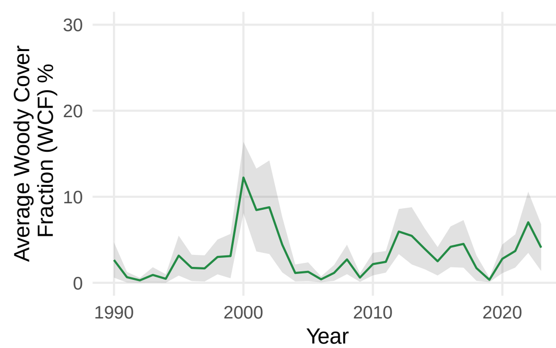

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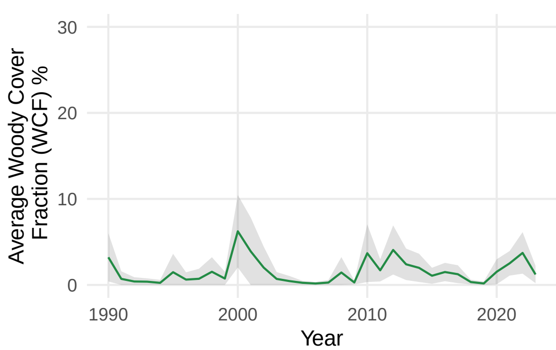

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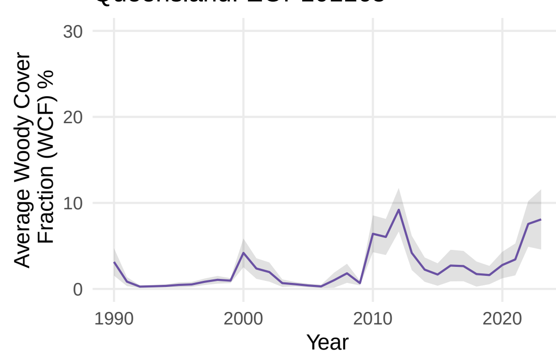

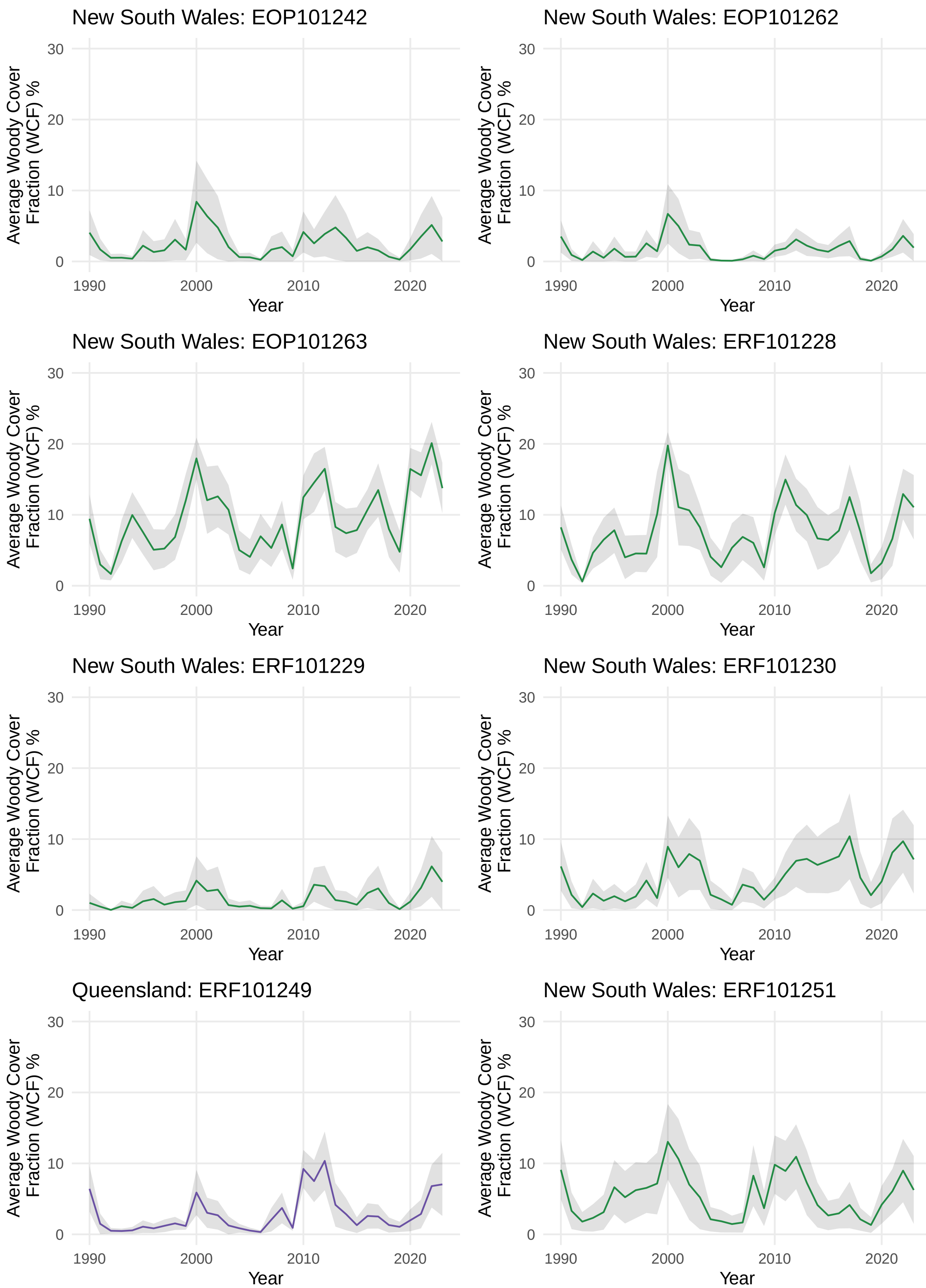
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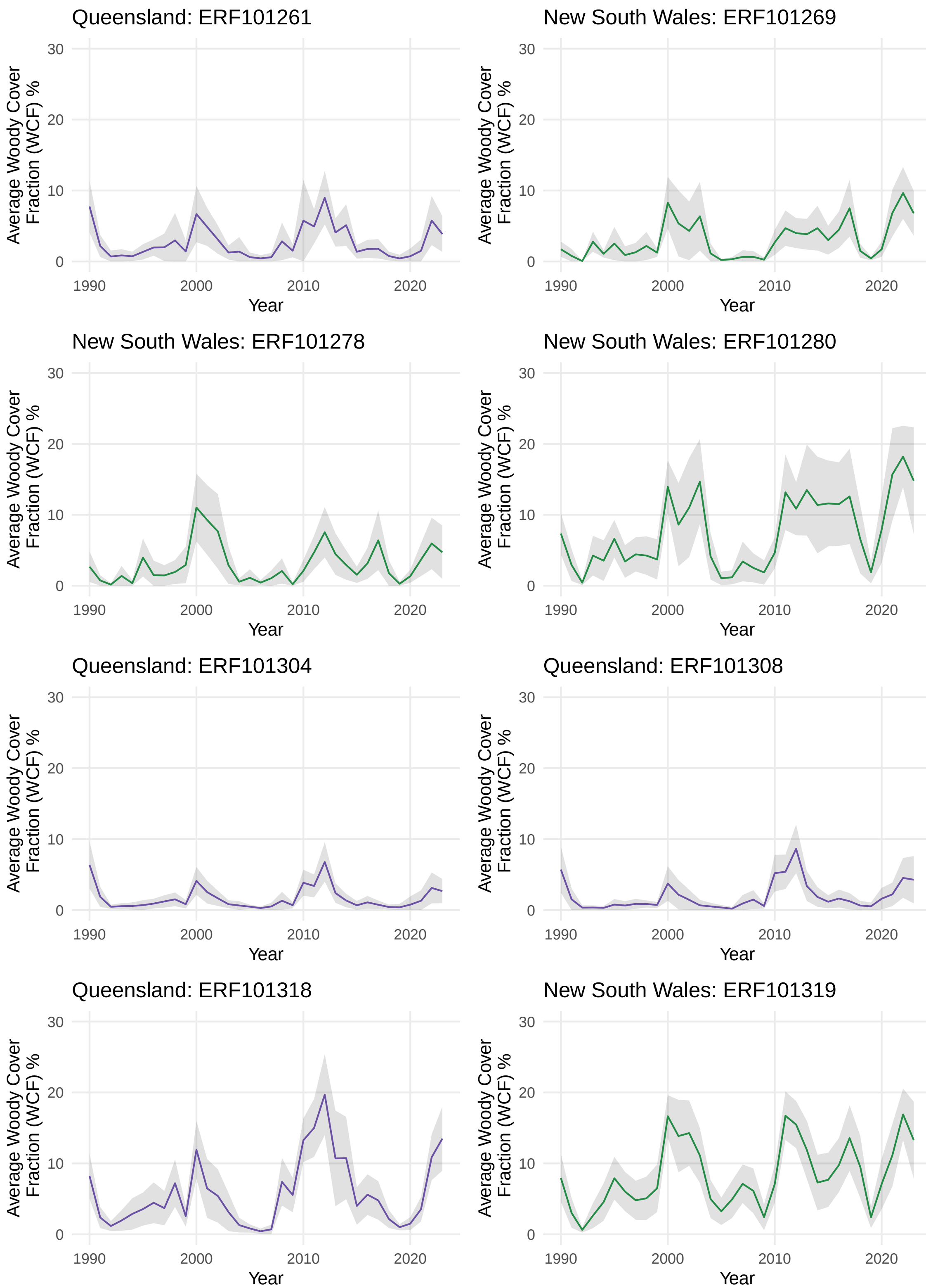
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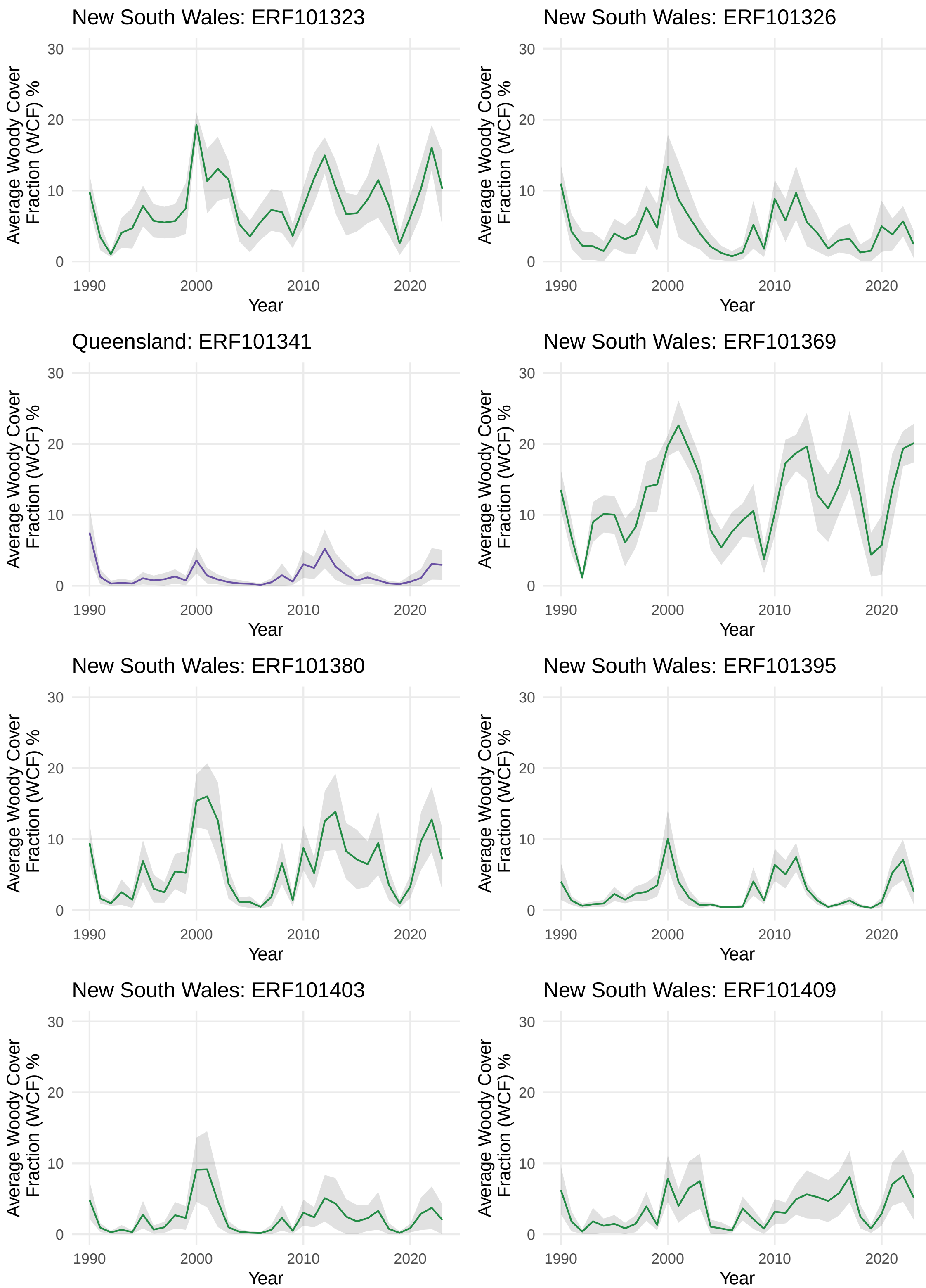
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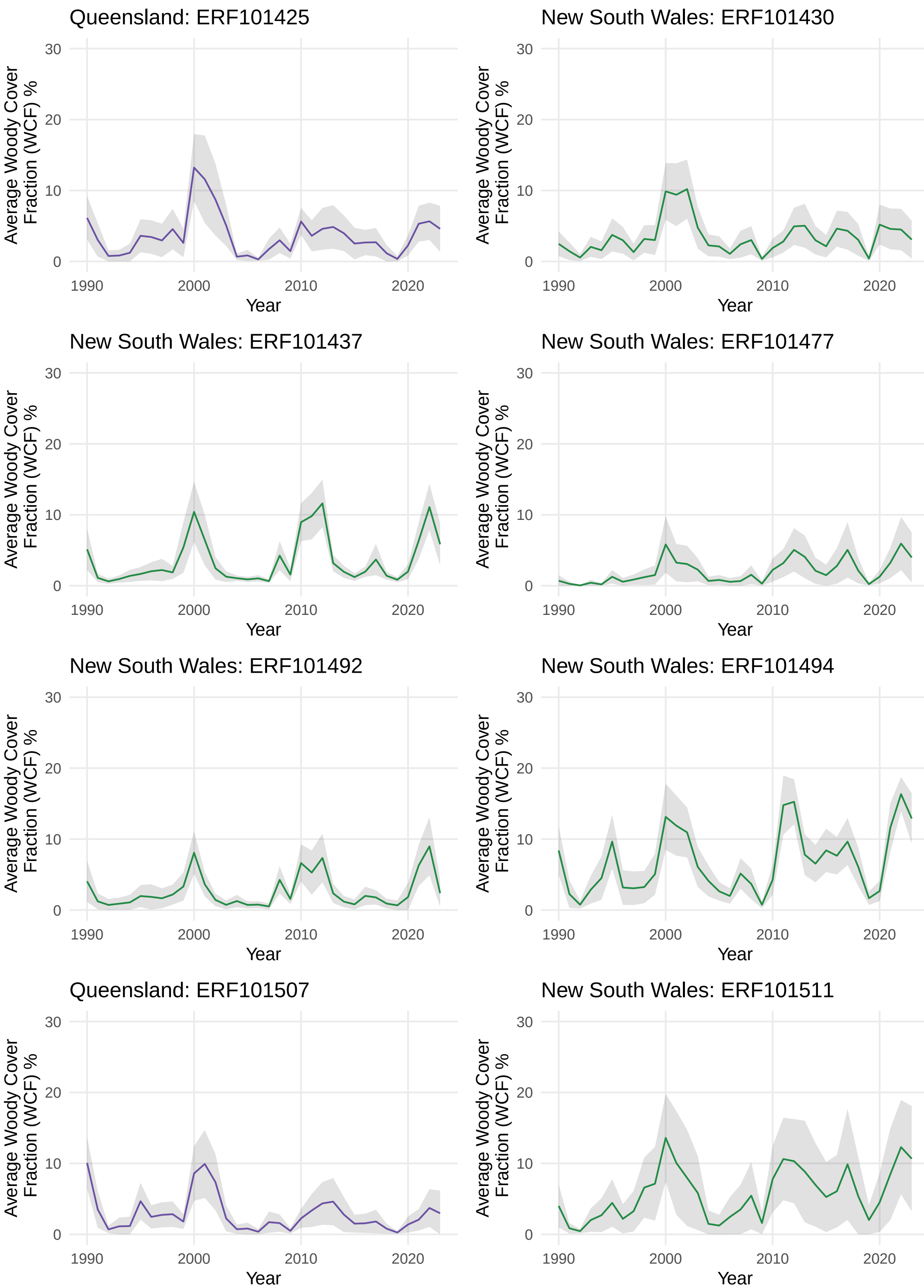
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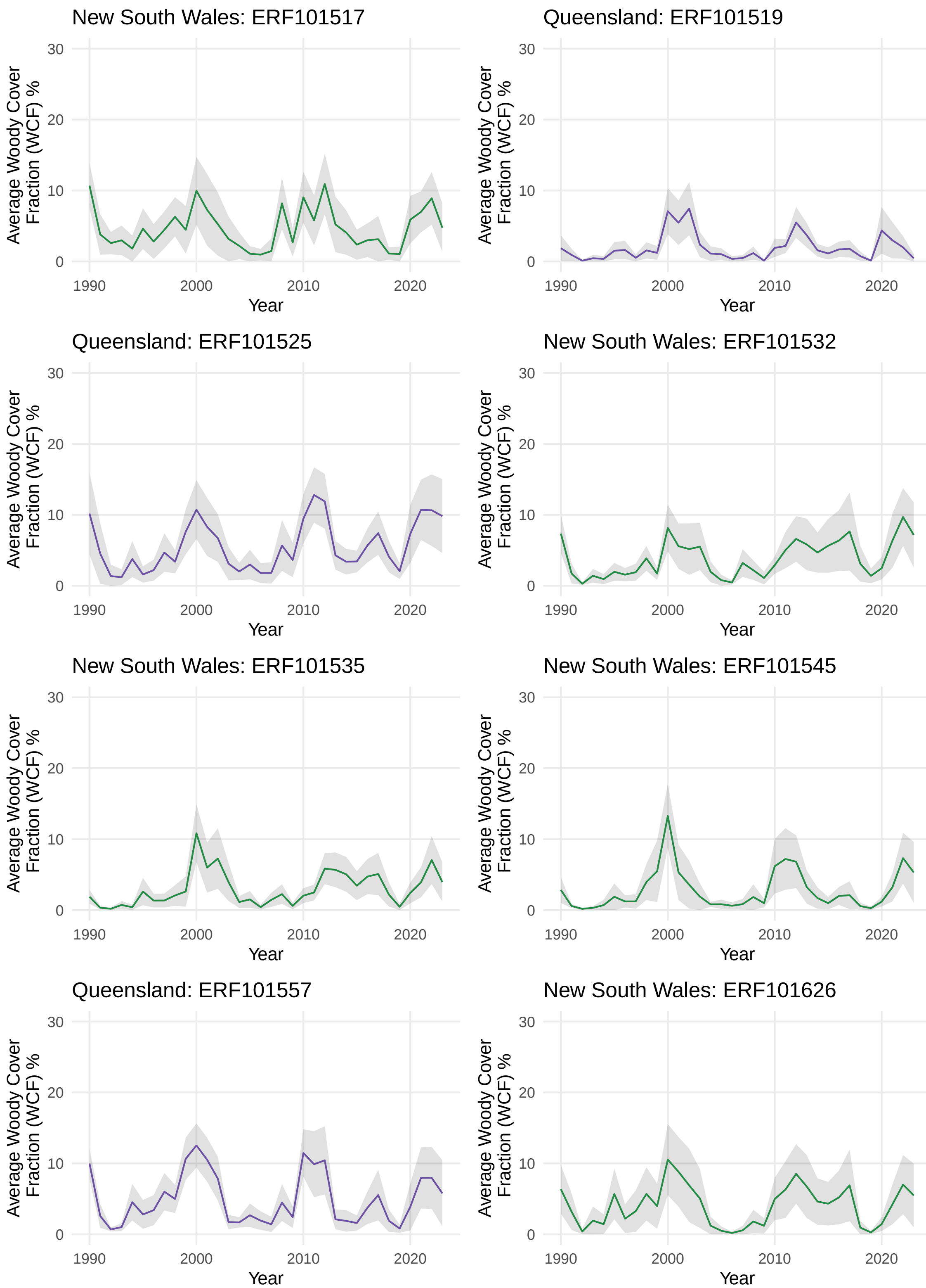
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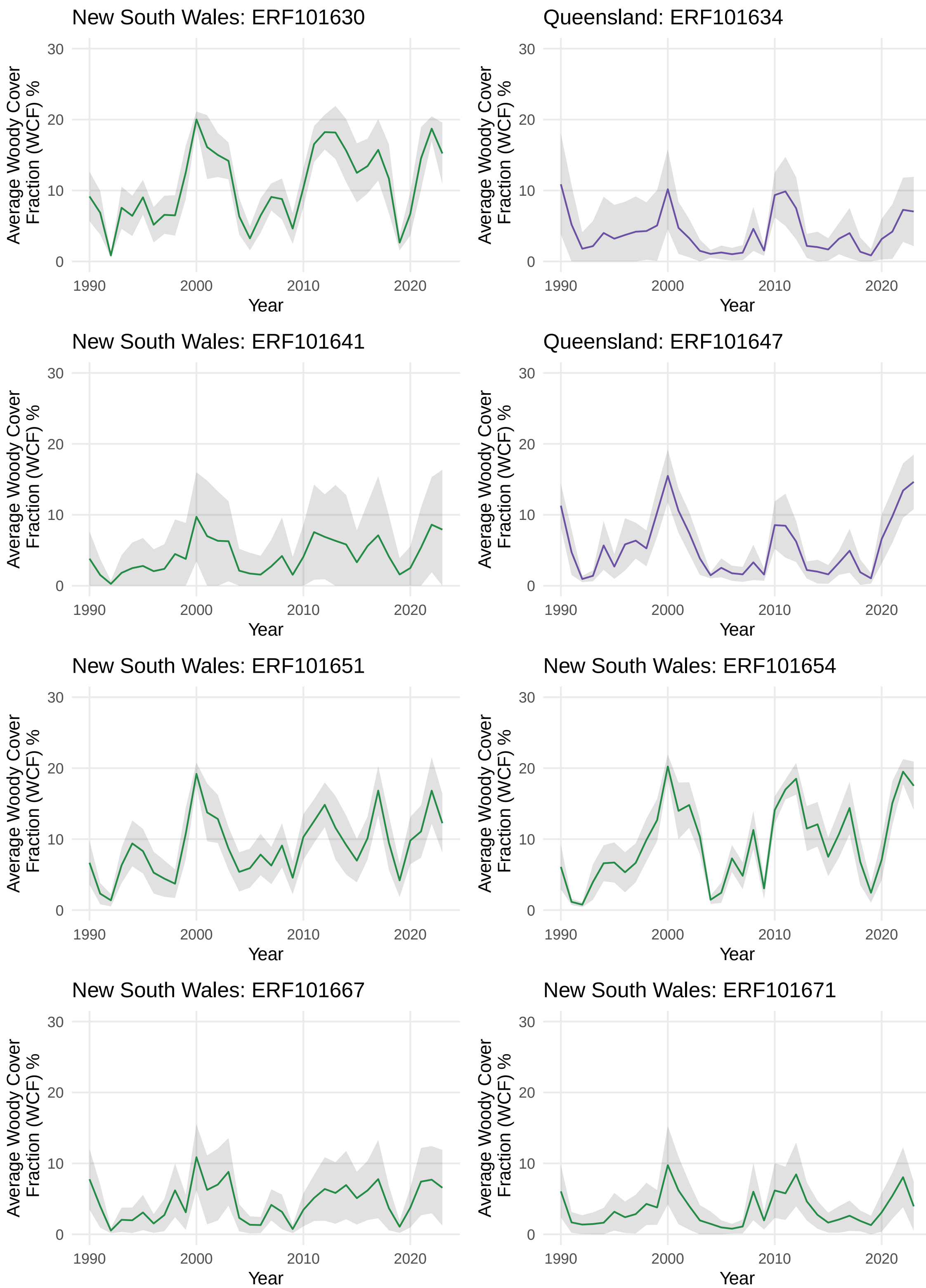
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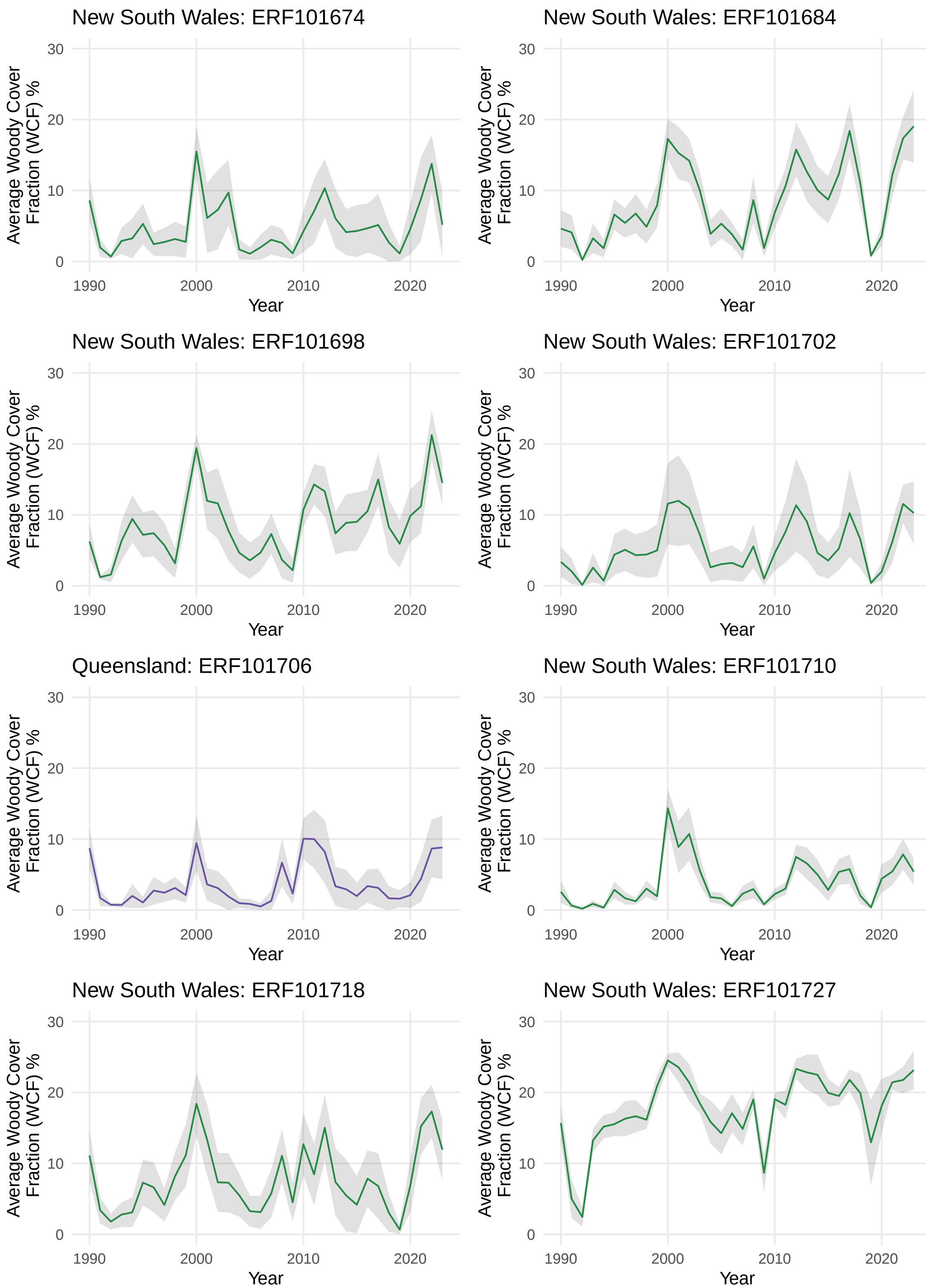
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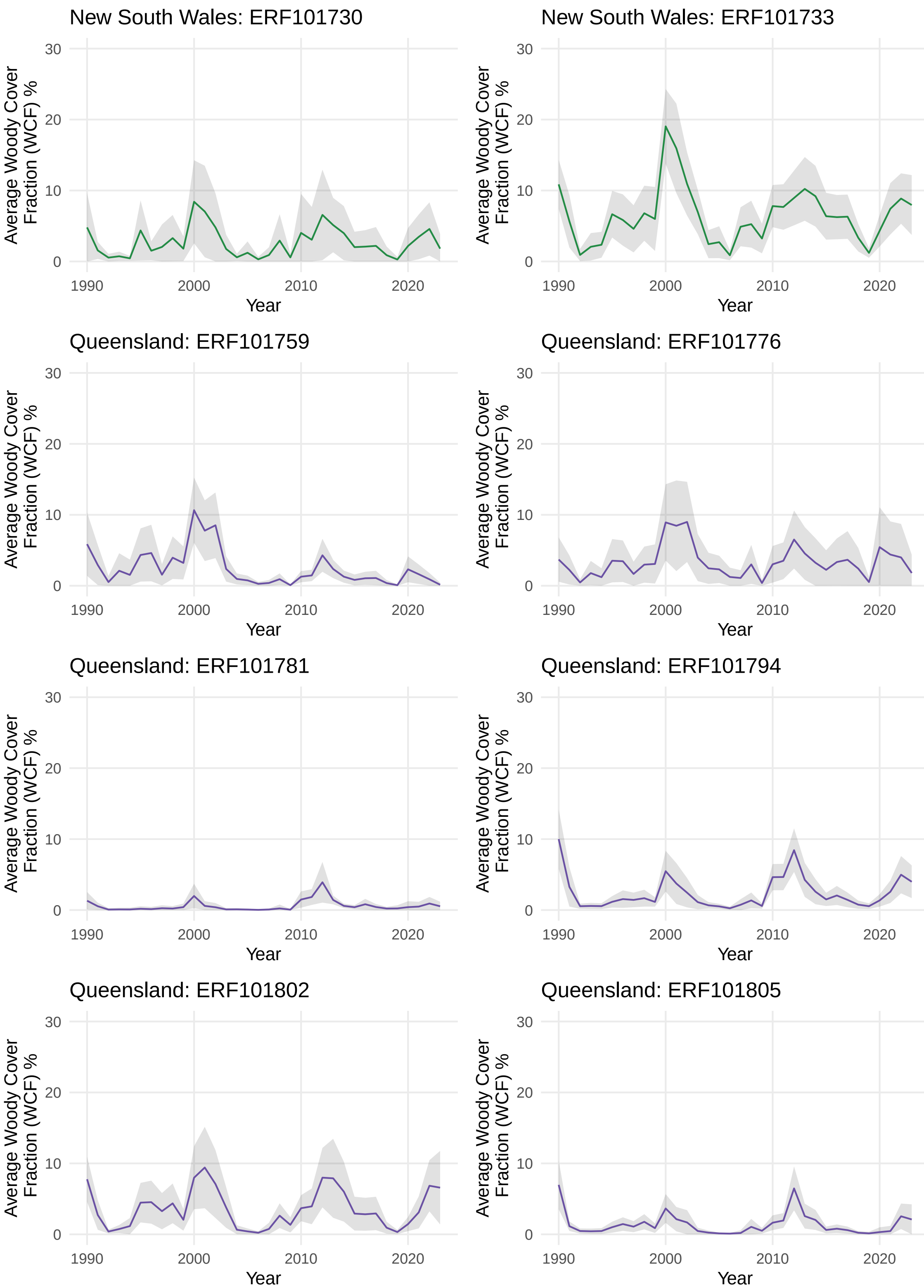
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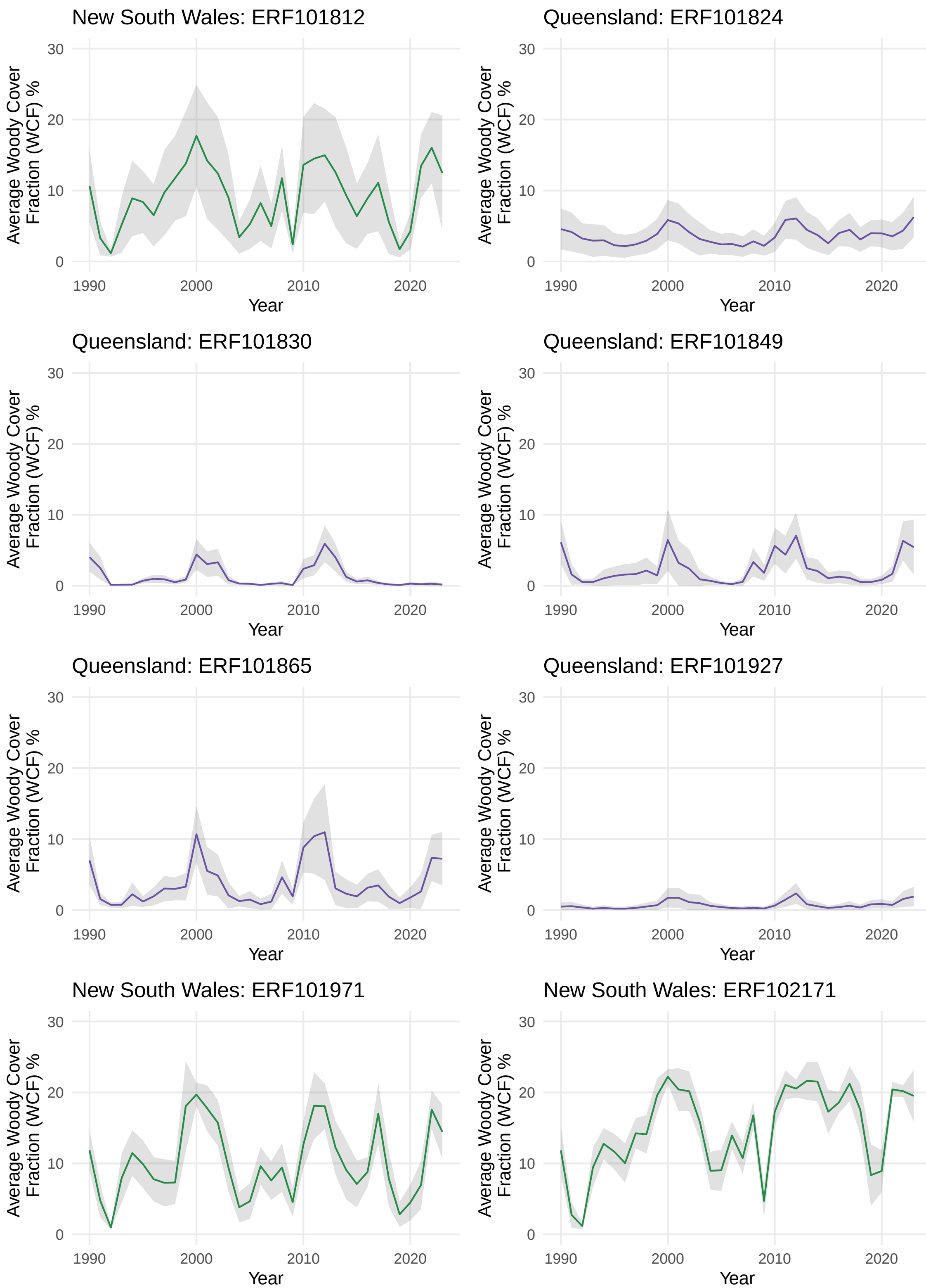
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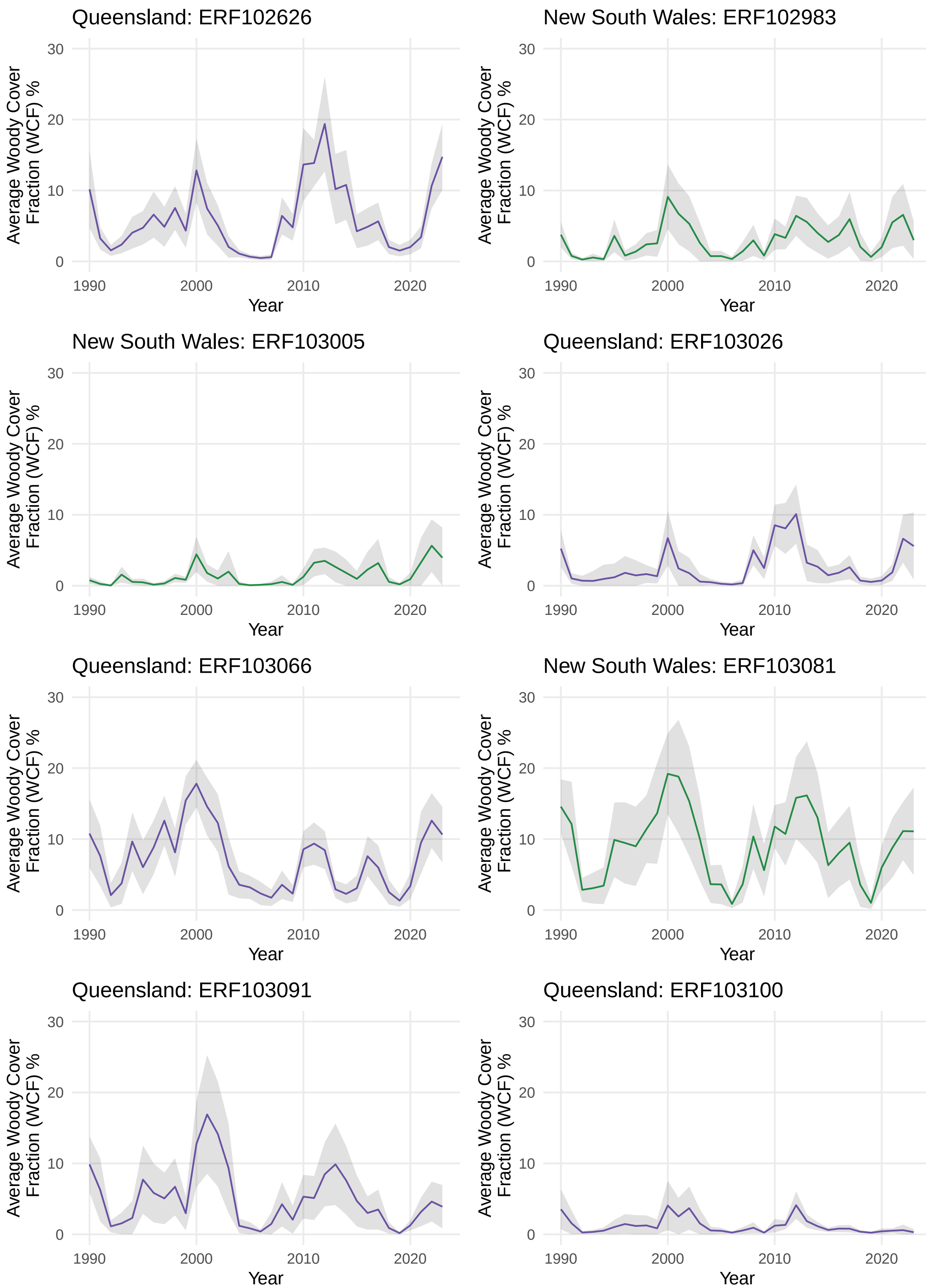
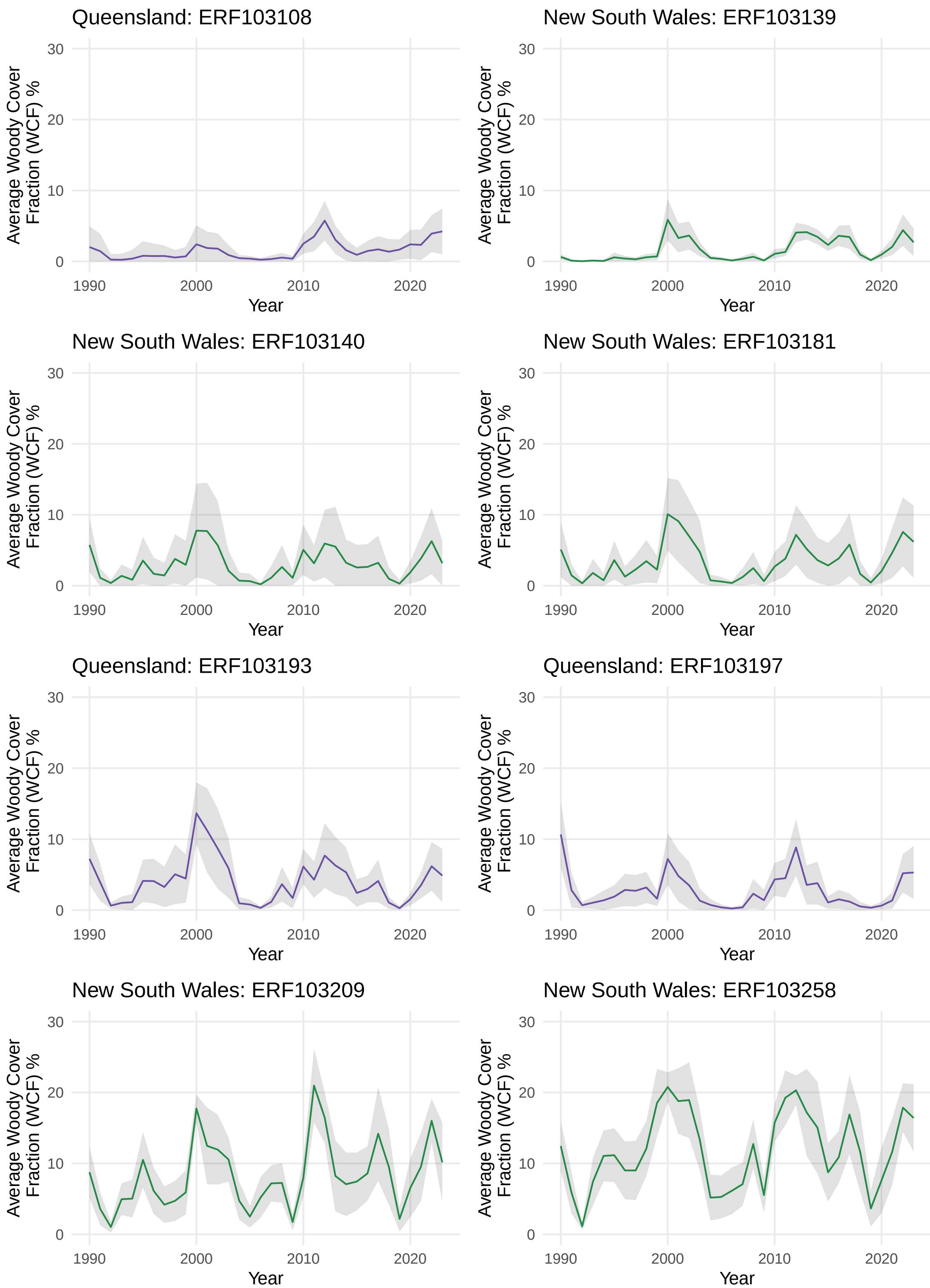
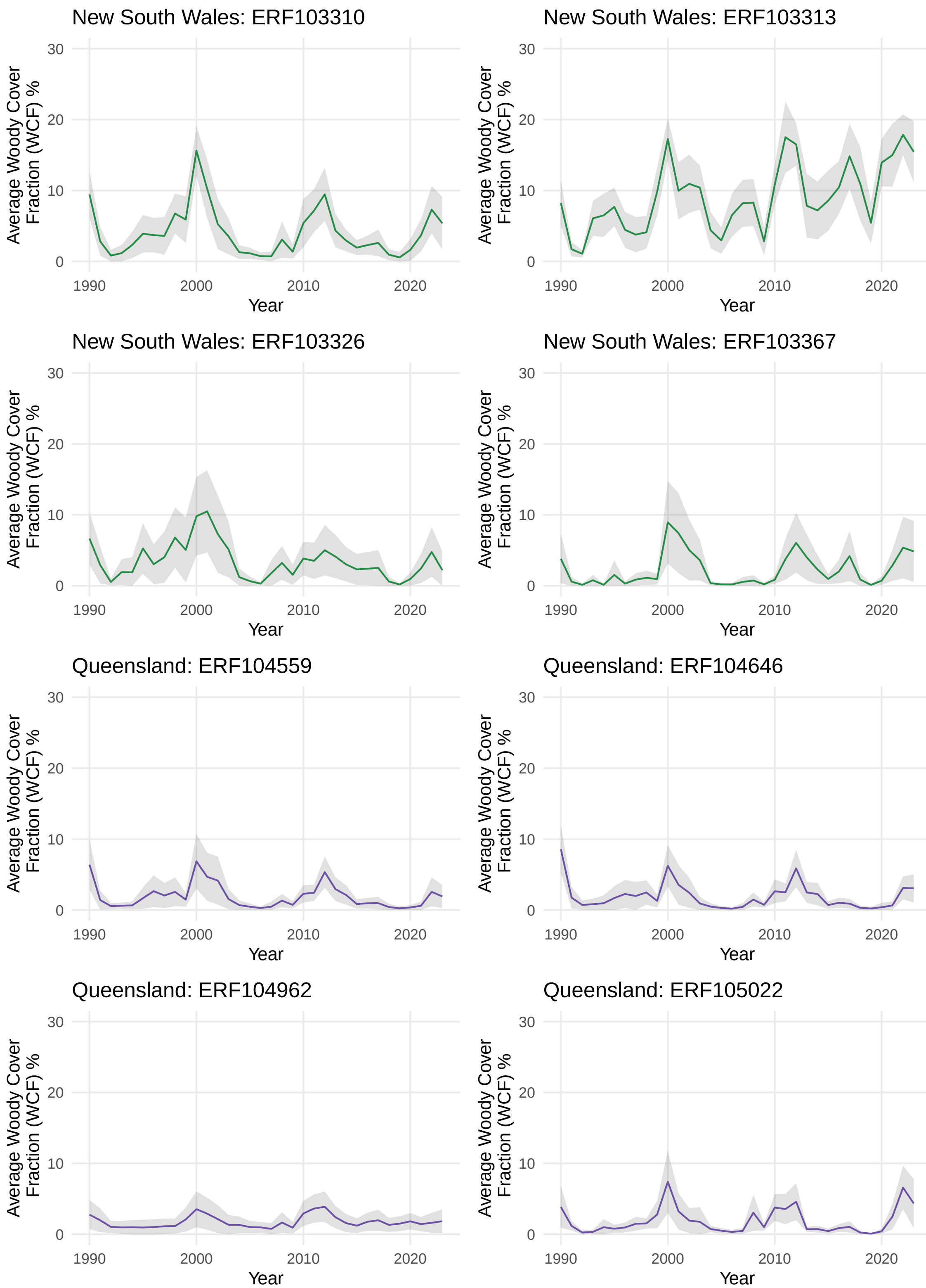
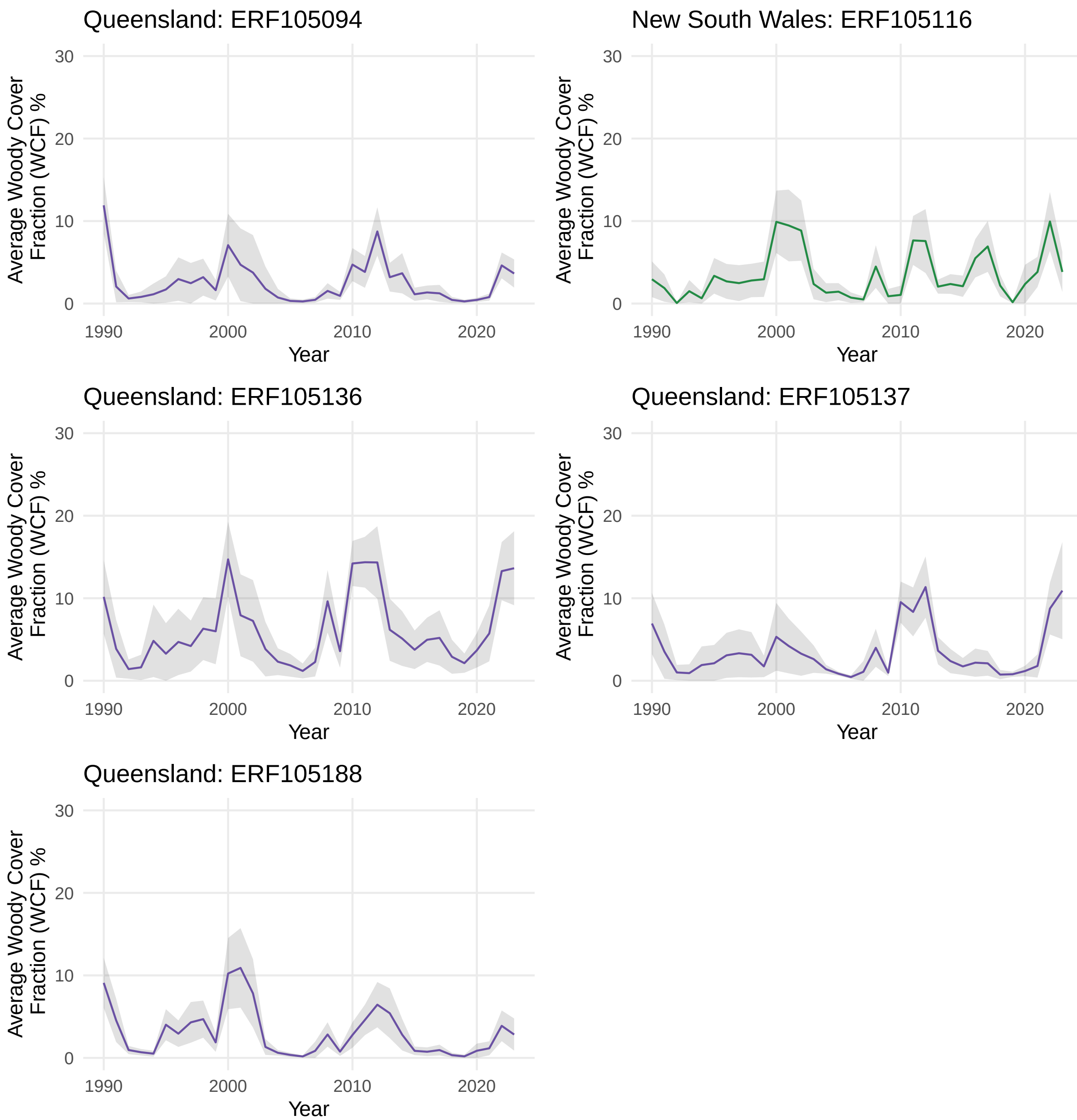
Average Woody Cover Fraction (WCF) %
Year
0
10
20
30
1990
2000
2010
2020


Queensland: ERF102626
New South Wales: ERF102983
New South Wales: ERF103005
Queensland: ERF103026
Queensland: ERF103066
New South Wales: ERF103081
Queensland: ERF103091
Queensland: ERF103100
Average Woody Cover Fraction (WCF) %
Year
0
10
20
30
1990
2000
2010
2020


Queensland: ERF103108
New South Wales: ERF103139
New South Wales: ERF103140
New South Wales: ERF103181
Queensland: ERF103193
Queensland: ERF103197
New South Wales: ERF103209
New South Wales: ERF103258
Average Woody Cover Fraction (WCF) %
Year
0
10
20
30
1990
2000
2010
2020


New South Wales: ERF103310
New South Wales: ERF103313
New South Wales: ERF103326
New South Wales: ERF103367
Queensland: ERF104559
Queensland: ERF104646
Queensland: ERF104962
Queensland: ERF105022
Average Woody Cover Fraction (WCF) %
Year
0
10
20
30
1990
2000
2010
2020


Queensland: ERF105094
New South Wales: ERF105116
Queensland: ERF105136
Queensland: ERF105137
Queensland: ERF105188
Average Woody Cover Fraction (WCF) %
0
10
20
30
1990
2000
2010
2020
Year