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ECOLOGICAL FUNCTION (J BAUHUS, SECTION EDITOR)

Materiality Assessment of Natural Capital Risks in Australian Forestry

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Abstract

Purpose of Review Natural capital is a term for the stocks of natural assets (e.g. natural resources and ecosystems) that yield flows of ecosystem services that benefit the economy and human well-being. Forestry is one of the industries with the greatest dependencies on natural capital, as well as having the potential for substantial positive or negative impacts on natural capital. These dependencies and impacts create direct risks to a forestry enterprise's ongoing financial viability, which translate into indirect risks for investors and society. There are growing demands from a variety of stakeholders for more reliable information to assess such risks, but at present, these risks are not always well understood, assessed or communicated in a consistent and comparable way. This paper addresses this problem by applying a standardized methodology to develop the first systematic, evidence-based review and financial materiality assessment of natural capital risks for the Australian forestry sector.

Recent Findings The vast potential scope of forestry impacts and dependencies on natural capital can be reduced to twenty key areas of relevance to Australian forestry, of which only seven to nine have been assessed as highly financially material for each of the sub-sectors of softwood plantations, hardwood plantations and native forestry. The majority of risks assessed as highly financially material are related to dependencies on natural capital. This is in part due to the fact that current regulations and certification schemes focus on managing impacts, but tend to overlook dependencies. Nearly all of the natural capital risks rated as highly material are likely to be exacerbated by climate change.

Summary An improved understanding of natural capital risks is an important input to better decision-making by forestry enterprises, as well as their lenders and investors, forestry regulators and other relevant stakeholders. This paper contributes to the preparedness of the forestry industry and its stakeholders to address questions about vulnerability to future changes and declining trends in natural capital.

Keywords Natural capital · Risk assessment · Materiality · Dependency · Impact · Forestry

Introduction

Businesses are increasingly affected by the consequences of depletion and degradation of the natural environment: directly through reduced availability of resources and services provided by the environment to their business, and indirectly via regulation and social concern about business impacts on the environment. This relationship between businesses and the environment is now commonly viewed through the lens of 'natural capital' [1–3]. The natural capital approach extends the economic notion of capital (resources which enable economic production) to the natural environment, which is conceptualized as stocks of natural capital (e.g. soil, minerals and ecosystems) supporting flows of environmental goods and ecosystem services (e.g. food production, crop pollination and flood mitigation). This

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approach goes beyond conventional environmental management thinking insofar as it encourages businesses to consider their dependencies on the environment, in addition to their impacts. There are growing demands from lenders, investors, policymakers, and other stakeholders for more reliable information to help them assess business impacts and dependencies on natural capital and to understand how this translates into business opportunities and risks [4, 5•].

Forestry is one of the industries with the greatest dependencies on natural capital [6•]: the health and productivity of forests are underpinned by ecosystem services provided by natural capital such as fertile soil, adequate water and suitable climate. Changes in the availability of natural capital can threaten the productivity of forests, and thus the ongoing financial viability of forestry enterprises. At the same time, forestry operations and activities have the potential to impact (positively or negatively) on natural capital. This can also affect the financial position of a forestry enterprise, for example when society responds to natural capital impacts through regulation (such as fines) or changes in consumer acceptance (such as restricted access to certain markets in the absence of sustainability certification). Dependencies and impacts on natural capital can therefore create a variety of direct operational and financial risks for forestry enterprises, which translate into indirect risks for private or public sector investors in those enterprises, as well as further indirect risks for society. In this paper we describe these risks as natural capital risks.

Many of these natural capital risks (for example, water availability, bushfire, pests and diseases) are well-known to forest growers and may already be considered in forest management and planning. Nevertheless, assessing these risks in a structured and consistent way offers forestry enterprises additional opportunities to integrate natural capital risk management into their decision-making and risk reporting. It also offers opportunities for standardized, consistent and comparable communication with stakeholders [4, 7]. At present, forestry natural capital risks are not well understood by all relevant stakeholders (for example, lenders, investors, regulators, policymakers and others), due to a lack of shared knowledge, inconsistencies in terminology and conceptual framing of the issues, and the fact that natural capital risks are often highly context-specific, leading to a lack of agreement about which risks are material for particular industries and locations. This paper addresses this problem by drawing on a standardized methodology for natural capital risk assessment [8], originally developed for agriculture, and extending it to forestry, in order to develop the first systematic, evidence-based financial materiality assessment of natural capital risks for the Australian forestry sector.

This paper identifies the casual pathways that link forestry activities and natural capital. For each pathway we review the evidence and use that review to systematically assess the financial materiality of each natural capital risk for the three main types of forestry in Australia: native forests, hardwood plantations and softwood plantations. The value perspective taken [2, 8] is that of a lender or investor, primarily focussed on the risk of adverse financial impacts on a forestry enterprise – as opposed to a broader social perspective [9]. For this assessment, risk mitigation activities were only considered if they were standard industry practices, in which case they were assumed to moderate the underlying risk according to typical outcomes from those practices. Our assessment presents the financial materiality of natural capital risks at a broad industry scale. It is likely that materiality assessments for individual forestry enterprises will vary depending on geographical location, management activities and the full suite of current and future mitigation strategies. The value of an industry-scale assessment is to provide a starting point for finer-scale assessments, as well as a sense of industry-scale risks for portfolio investors.

The paper is structured as follows. In the next section, we discuss key concepts in natural capital risk assessment, such as impact and dependency pathways and materiality. We then set out our methodology for conducting our materiality assessment of natural capital risks for Australian forestry, followed by our results and discussion of our findings and conclusions in the final section.

Key Concepts in Natural Capital Risk

Natural capital risk assessment is a relatively new concept, and consistency in approaches has only recently begun to emerge. The Natural Capital Protocol [2] provides a generic approach to undertaking any type of natural capital assessment, including risk assessment, although it does not provide specific guidance on how to do this. A supplement to the Protocol, tailored to the forest products sector, is also available [10]. More specific guidance, based on the Natural Capital Protocol, has been developed by the Natural Capital Finance Alliance (NCFA) for portfolio risk assessment [6, 11] and individual asset-level risk assessment in agriculture [12•]. Here, we build on the existing approaches (in particular [12•]) to undertake a materiality assessment of natural capital risks for Australian forestry. Materiality assessment is a common step in any type of assessment which requires some narrowing down of scope to that which is most relevant according to the assessment's objectives [2]. For example, it can help identify the risks that should be prioritized for further analysis or management response.

The concept of materiality has been adopted from the field of accounting [13, 14]. Broadly, something is 'material' if it has reasonable potential to significantly alter the decisions being taken by a user of the information being reported. In a financial accounting context, a materiality assessment is used to determine whether or not an item should be included in a financial report. Even within the context of financial reporting, however, the scope of issues that are considered to be material is broadening beyond financial matters to include environmental and social factors, and the timeframes over which materiality is assessed are changing to incorporate previously unaccounted medium and long-term issues (e.g. climate change) [7]. The concept of materiality is also a key feature in a variety of sustainability assessment and reporting frameworks, such as the Global Reporting Initiative (GRI) framework [15] and the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) [16]. There are three distinct interpretations of materiality now in use that are relevant to corporate accounting and reporting: the narrowly defined purely financial scope, a broader scope of sustainability issues that are financially material for enterprise value creation, and a still broader scope of issues that are material from a social perspective [17]. We adopt the second of these interpretations, which is in keeping with the value perspective of a typical lender or investor.

Any assessment of materiality is to some degree subjective and context-dependent [13]. Unless a risk is already well understood – which is not the case for most natural capital risks – assessing the materiality of a risk essentially requires undertaking a preliminary or high-level risk assessment. This requires, firstly, an understanding of the causal pathways that link specific business activities and natural capital, known as impact and dependency pathways [2], and secondly, assessing the likelihood and magnitude of possible changes in these pathways that may lead to adverse financial outcomes for the enterprise. The concept of impact pathways is well developed [2, 18]: it involves identifying impact drivers (which may be inputs to the business, such as water use, or outputs, such as emissions), the environmental outcomes or changes in natural capital that result from the impact driver (e.g. an increase in levels of a pollutant), and the resulting societal impacts (e.g. health problems). In order to link changes in natural capital or societal impacts back to adverse financial outcomes for the enterprise, however, we must consider the possibility of either a direct feedback to ecosystem services that the company relies on (the 'ecosystem response' pathway in Fig. 1) or a societal response such as regulation, either of which can affect the company's financial position. The concept of dependency pathways is somewhat less well developed, but we can likewise identify pathways that lead from various threats of environmental or social change (e.g. a build-up in chemicals which are harmful to pollinating insects) to changes in natural capital (e.g. fewer pollinating insects), which in turn affects the availability of ecosystem services (e.g. pollination) on which a business depends.

We take a broad view of ecosystem services including provisioning (e.g. production of timber), regulating (e.g. water regulation), cultural (e.g. recreation) and supporting (e.g. soil formation) services [3]. In some cases, the relevant 'service' might be the *absence* of conditions that would otherwise be unfavourable (such as extreme weather). Likewise, some aspects of nature may have negative effects on a business (such as pests and diseases) and can therefore be considered to provide 'ecosystem dis-services' [19]. These are also important to consider from a risk perspective.

Assessing the materiality of a potential *risk* is different to assessing the materiality of a dependency (as per [6•]) or an impact (as per [18]), because it requires not only an understanding of causal pathways, but also an assessment of the likelihood and magnitude of consequences that could result from changes in those pathways. However, in the case of an industry-level risk materiality assessment, it is not necessary to evaluate in detail the likelihood of a risk occurring: it is sufficient to consider whether the occurrence of a risk is plausible within the selected industry and geography, over a relevant time-scale. We considered a risk to be plausible if it has occurred in the past or in similar situations elsewhere,

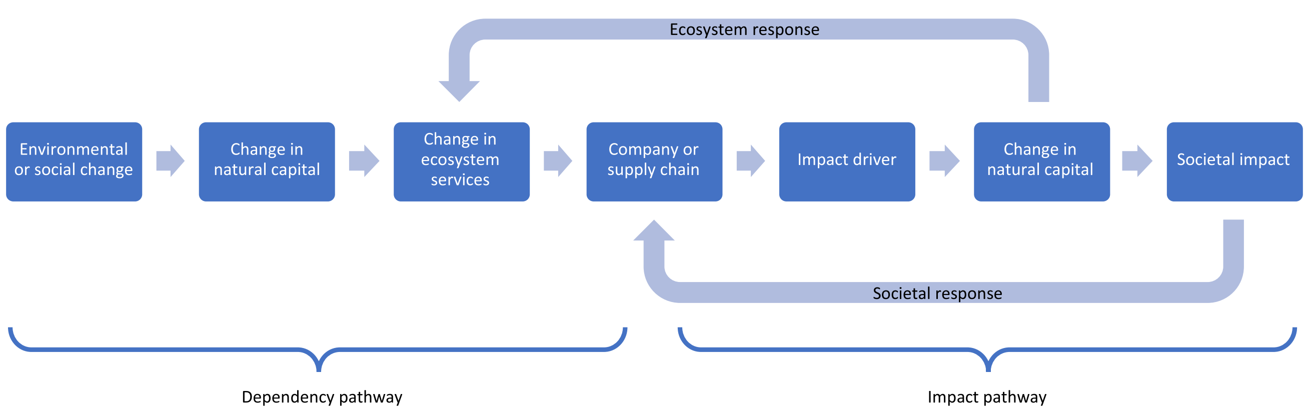


Fig. 1 Dependency and impact pathways. Source: [8]

or if it is projected to occur in future, which we defined as approximately the next 30 years. If the likely future occurrence of a risk is scientifically highly uncertain, we erred on the side of caution and considered it plausible. This interpretation of likelihood allows us to focus our assessment on business outcomes, which we define as adverse financial impacts on a typical forestry enterprise resulting from a change to an ecosystem service on which such an enterprise depends, or a change to an impact driver that such an enterprise causes.

Methodology: A Combined Evidence-Based and Expert-Review Assessment of Financial Materiality

Our approach was iterative and open to either including new impacts or dependencies, or rejecting initial assumptions as further evidence was gathered. For each potentially material direct impact driver and ecosystem service we mapped out the impact or dependency pathway using the approach illustrated in Fig. 1. A major challenge facing any evidence-based assessment of natural capital risks is the general paucity of evidence that explicitly links impact or dependency pathways to the financial performance of forestry enterprises. To rectify this, our evidence collation was conducted in stages. We initially searched in both peer-reviewed and grey literature for each potentially material dependency or impact. Initial keyword searches (searched via Web of Science and Google Scholar for peer-reviewed and via Google for grey literature) were then supplemented by 'snowballing' from the reference lists of identified papers and reports. The outcomes of the initial evidence search were then reviewed through detailed discussions with approximately 15 forestry industry experts and representatives from forestry enterprises. This process allowed us to validate the initial evidence, identify any gaps and identify additional evidence which was subsequently reviewed and incorporated into the analysis. The evidence gathered was either focused specifically on Australian forestry or had broader applicability, including for Australian forestry.

Our assessment of financial materiality followed a standardized approach based on the totality of the evidence reviewed. For both impact and dependency pathways, the link between natural capital and financial risks for enterprises can be broken down into just two components, which are then combined. For dependency risks, we assessed (1) the *degree of dependency* of a forestry enterprise on the relevant stock of natural capital or flow of ecosystem services and (2) the *severity of threats* (both the current threats and any future changes, for example from climate change) to the same. For impact risks, we assessed (1) the *degree of impact* of forestry operations on the relevant stock of natural capital or flow of ecosystem services and (2) the *severity of consequences* of the impact (both the current and potential future changes to the financial viability of the forestry enterprise).

The degree of dependency was assessed by considering to what extent the enterprise could continue to be financially viable without the relevant ecosystem services (high/medium/low: disruption of the ecosystem services could result in severe/moderate/limited financial loss). This is broadly comparable to, but simpler than, the approach used by the NCFA for portfolio risk assessment [6•]. The severity of threat was assessed by considering the probability and magnitude of current threats and plausible changes for the future availability of the relevant ecosystem services. Again, this is broadly comparable to, but simpler than, the NCFA approach which involves combining separate assessments of the importance of natural capital assets to ecosystem services, and the influence of drivers of environmental change on natural capital [6•]. However, the NCFA approach does not consider probability. Factors such as the sensitivity of the natural capital asset to changes and the reversibility of such changes [6•] were taken into account in considering the magnitude of the threat. These elements have been combined as shown in Fig. 2, based on a simple rule whereby a high (low) severity rating increases (decreases) the degree of impact/dependency rating, while a moderate severity rating leaves the degree of impact/dependency rating unchanged.

The degree of impact was assessed by considering to what extent the relevant stock of natural capital or flow of ecosystem services could continue to function after a plausible impact. A high/moderate/low degree of impact would indicate the natural capital or ecosystem service is likely to be severely/moderately/minimally damaged. The severity of consequences was assessed based on how significantly the enterprise could be affected by societal responses (such as regulation or social concern) to any changes in natural capital or ecosystem services, and also by any ecosystem

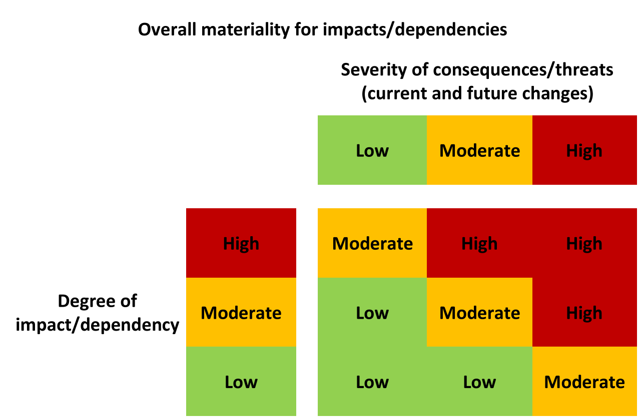


Fig. 2 Method used to combine the degree of impact/dependency and the severity of consequences/threats to determine financial materiality

response which affects natural capital and ecosystem services that the business relies on, using the same financial loss criteria as used to assess degree of dependency.

Risk mitigation options for both impact and dependency risks were taken into account only if they were standard industry practices, in which case they were assumed to moderate the underlying risk according to typical outcomes from those practices. The rationale for this is that only standard industry practices can be assumed to be widely practiced and therefore applicable at the scale of this assessment.

We assessed the financial materiality associated with each pathway separately for softwood plantations, hardwood plantations and native forests, due to the different management systems used.

Finally, we evaluated the level of confidence (quantity, quality and consensus) in the evidence, following the four-box model adopted from IPBES [20] (Fig. 3). The four terms used to summarize the level of confidence are: *well established*, which represents robust evidence with high levels of agreement; *unresolved*, which represents robust evidence but with low agreement or contrasting conclusions; *established but incomplete*, which represents limited evidence, with high levels of agreement; and *inconclusive*, which represents limited or no evidence and little agreement. This qualitative assessment of the level of confidence in the evidence provides additional information to help users prioritize which risks are most important to assess, and where further research could be of most value (e.g. topics where the risks are highly material but the level of confidence in the evidence is low).

Results

Through the literature and expert review, we identified ten dependency and ten impact pathways associated with potentially financially material risks for Australian forestry. The review identified dependency pathways where natural capital provides services that contribute positively to forestry production processes (for example, water availability, suitable growing temperature or soil quality); in addition to dependency pathways where the service is the absence of negative effects (for example, bushfire, pests and diseases or weeds). The review also identified impact pathways from forestry activities that lead to changes in natural capital and ecosystem services, most of which are relevant due to societal responses to these impacts, such as regulation (for example, downstream water quality and quantity, or biodiversity) but some of which can directly affect the forestry business (for example, through on-site changes in soil quality). The risk definitions along with their associated dependency or impact pathways are summarized in Tables 1 and 2. The final column of each table shows the links to other risk topics, recognizing that there are often many interlinkages between causal pathways in complex systems (for further detail on the interlinkages between natural capital risk topics see: [21]).

The evidence used to assess the financial materiality of each dependency and impact risk is summarized in Tables 3 and 4. In accordance with our framework for financial materiality assessment, each table separates the evidence into that which addresses the degree of dependency/impact a typical

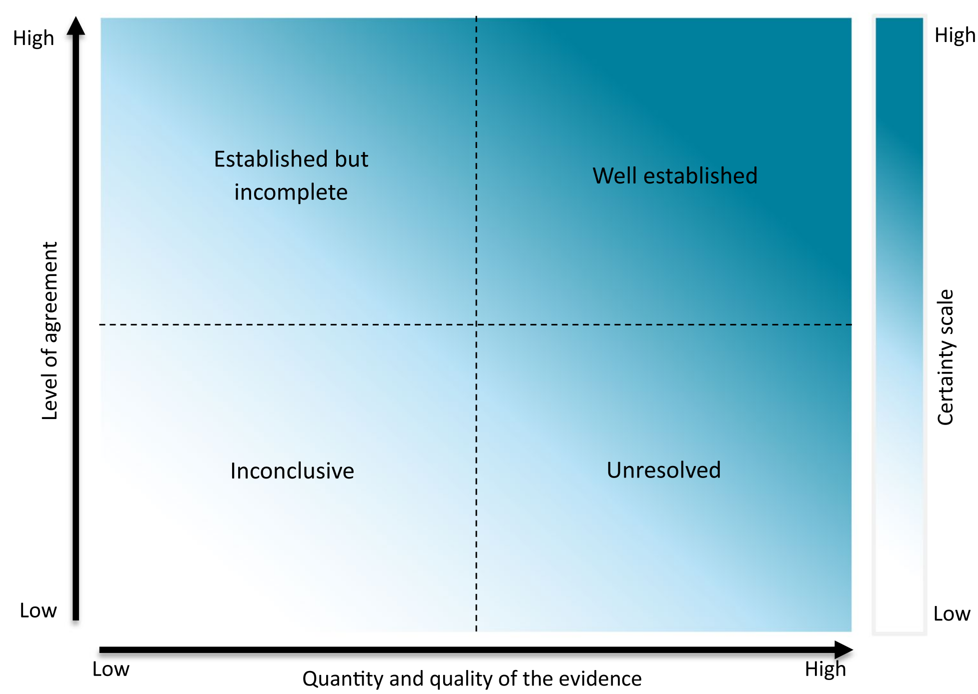


Fig. 3 Level of confidence based on the four-box model in IPBES [20]. The level of confidence increases towards the top-right corner as shown by the increased strength of the shading

Table 1 Summary of natural capital dependency risks and associated causal pathways for Australian forestry

Thematic area	Risk Topic	Definition The risk of lower productivity and/or increased costs due to:	Pathway: (Threat >> Natural Capital >> Ecosystem Service >> Reduced revenue and/or increased costs for forestry enterprise)	Links to other risks
Water	Water availability (dependency)	Rainfall, or groundwater resources, being insufficient to produce the target volume and quality of harvestable biomass.	Climatic conditions, climate change and changes in demand for water from others >> Changes in rainfall and groundwater recharge >> Changes in tree growth and tree mortality >>	Dependency risks: temperature, bushfire, soil quality, fertilizer, weeds, pests and diseases Impact risks: water use, bushfires, soil quality, weeds, pests and diseases, greenhouse gases.
Weather and climate	Temperature (dependency)	Exposure to changes in average temperatures, or temperature extremes.	Climatic conditions and climate change >> Changes in mean and extreme temperatures (including heat waves and unseasonable winter warmth) >> Changes in tree growth and tree mortality >>	Dependency risks: water availability, bushfire, soil quality, biodiversity, pests and diseases Impact risks: water use, bushfires, soil quality, biodiversity, pests and diseases, greenhouse gases.
	Bushfires (dependency)	Exposure to bushfires.	Climatic conditions and climate change and changes in societal burning practices >> Heat waves, drought and a longer fire season >> Changes in bushfire frequency and severity leading to increased tree damage or mortality >>	Dependency risks: water availability, temperature, storms and floods, soil quality, biodiversity, weeds, pests and diseases. Impact risks: water quality, bushfires, soil quality, biodiversity, weeds, pests and diseases, greenhouse gases, other air emissions.
	Storms and floods (dependency)	Exposure to storms and floods, for example floods, wind, hail, snow, cyclones.	Climatic conditions and climate change >> Changes in atmospheric conditions and weather patterns >> Changes in frequency and severity of storms and floods leading to increased tree damage or mortality >>	Dependency risks: bushfires, soil quality, biodiversity, pests and diseases. Impact risks: water quality, bushfires, soil quality, biodiversity, pests and diseases.
Land and soil	Soil quality (dependency)	Poor soil quality.	Climatic conditions, climate change and forestry operations >> Changes in soil properties and soil erosion >> Changes in availability of nutrients/moisture leading to reduced tree growth and tree mortality >>	Dependency risks: water availability, temperature, bushfires, storms and floods, fertilizer, biodiversity, weeds. Impact risks: water quality, bushfires, soil quality, contamination, biodiversity, weeds, greenhouse gases.
	Fertilizer use (dependency)	Non-renewable inputs to fertilizer being less available or priced at higher levels in future.	Changes in global supply-demand for fertilizer inputs >> Changes in fertilizer availability or price >> Reduced tree growth >>	Dependency risks: water availability, soil quality, weeds. Impacts risks: water quality, soil quality, weeds, greenhouse gases.

Table 1 (continued)

Thematic area	Risk Topic	Definition The risk of lower productivity and/or increased costs due to:	Pathway: (Threat >> Natural Capital >> Ecosystem Service >> Reduced revenue and/or increased costs for forestry enterprise)	Links to other risks
Biodiversity and ecosystems	Biodiversity (dependency)	Loss of ecosystem services provided by biodiversity.	Climatic conditions and climate change, forestry operations and landscape-level changes >> Changes in abundance and distribution of key species >> Changes in the provision of services from biodiversity, e.g. pollination >>	Dependency risks: temperature, bushfires, storms and floods, soil quality, weeds, pests and diseases. Impact risks: bushfires, soil quality, biodiversity, weeds, pests and diseases.
	Weeds (dependency)	Competition from weeds.	Climatic conditions, climate change, forestry operations and landscape-level changes >> Changes in abundance and distribution of weeds >> Competition from weeds leading to reduced tree growth >>	Dependency risks: water availability, bushfires, soil quality, fertilizer, biodiversity. Impact risks: bushfires, soil quality, biodiversity, weeds.
	Pests and diseases (dependency)	Damage from pests and diseases.	Climatic conditions, climate change and landscape-level changes >> Changes in abundance and distribution of pests and diseases and introduction of new pests and diseases >> Reduced tree growth and increased tree mortality >>	Dependency risks: water availability, temperature, bushfires, storms and floods, biodiversity. Impact risks: bushfires, biodiversity, pests and diseases.
Energy	Energy (dependency)	Inefficient use of energy and/or higher prices of energy inputs.	Changes in energy supply, demand and/or efficiency >> Changes in energy availability or price >> Changes in relative operational energy efficiency >>	Impact risks: greenhouse gases.

Table 2 Summary of natural capital impact risks and associated causal pathways for Australian forestry

Thematic area	Risk Topic	Definition The risk of business consequences arising from the following impacts on natural capital, when:	Pathway (Impact Driver > > Natural Capital > > Societal Impacts > > Business Consequences)	Links to other risks
Water	Water use (impact)	Water used is non-renewable, extracted beyond its renewal rate, or diverted away from other ecosystem uses.	Forest establishment, management and harvesting > > Changes in surface and groundwater flows > > Changes in water available for others, social concern and changes to regulation > > Increased costs and forest operations or activities restricted.	Dependency risks: water availability, temperature.
	Water quality (impact)	Forestry activities negatively affect the quality of surface or sub-surface water.	Forest establishment, management and harvesting > > Changes in water quality (e.g. increased turbidity) > > Changes in water quality for others, health impacts, social concern and changes to regulation > > Increased costs, loss of certification and market access.	Dependency risks: bushfires, storms and floods, soil quality, fertilizer. Impact risks: bushfires, soil quality, contamination and waste.
Weather and climate	Bushfire (impact)	Forestry activities increase the incidence of fire in surrounding areas.	Use of fire or accidental ignition of fire > > Fire damage to surrounding areas > > Impacts on life, health and property, social concern and changes to regulation > > Increased costs (litigation, insurance, management).	Dependency risks: water availability, temperature, bushfires, storms and floods, soil quality, biodiversity, weeds, pests and diseases. Impact risks: water quality, soil quality, biodiversity, weeds, pests and diseases, greenhouse gases, other air emissions.
Land and soil	Soil quality (impact)	Forestry activities negatively affect soil quality.	Forest establishment, management and harvesting > > Increased soil compaction, reduced soil nutrients, organic carbon and soil biodiversity > > Social concern and changes in regulation > > Increased costs, loss of certification and market access.	Dependency risks: water availability, temperature, bushfires, storms and floods, fertilizer, biodiversity, weeds. Impact risks: water quality, bushfires, soil quality, contamination, biodiversity, weeds, greenhouse gases.
	Contamination and waste (impact)	Land is contaminated with various forms of waste.	Forest management and harvesting > > Changes in soil properties and build-up of chemicals > > Social concern and changes in regulation > > Increased costs, loss of certification and market access.	Dependency risks: soil quality. Impact risks: water quality, soil quality.

Table 2 (continued)

Thematic area	Risk Topic	Definition The risk of business consequences arising from the following impacts on natural capital, when:	Pathway (Impact Driver >> Natural Capital >> Societal Impacts >> Business Consequences)	Links to other risks
Biodiversity and ecosystems	Biodiversity (impact)	Forestry activities negatively affect biodiversity or habitats.	Forest establishment, management, and harvesting >> Changes in abundance and distribution of biodiversity >> Social concern and changes in regulation >> increased costs, loss of certification and market access.	Dependency risks: temperature, bushfires, storms and floods, soil quality, biodiversity, weeds, pests and diseases. Impact risks: bushfires, soil quality, weeds, pests and diseases.
	Weeds (impact)	Forestry activities increase the incidence or impact of weeds.	Forest establishment, management, and harvesting >> Changes in abundance and distribution of weeds >> Weed infestations in surrounding areas, social concern and changes in regulation >> Increased costs, loss of certification and market access.	Dependency risks: water availability, bushfires, soil quality, fertilizer, biodiversity, weeds. Impact risks: bushfires, soil quality, biodiversity.
	Pests and diseases (impact)	Forestry activities increase the incidence or impact of pests and diseases.	Forest establishment, management, and harvesting >> Changes in abundance and distribution of pests and diseases >> Outbreaks in surrounding areas, social concern and changes in regulation >> Increased costs, loss of certification and market access.	Dependency risks: water availability, temperature, bushfires, storms and floods, biodiversity, pests and diseases. Impact risks: bushfires, biodiversity.
Air emissions	Greenhouse gas emissions (impact)	Greenhouse gas emissions are priced at higher levels in future, or limited by regulations.	Forest establishment, management, and harvesting >> Changes in greenhouse gas concentration in the atmosphere >> Climate change impacts, social concern and changes in regulation >> Increased costs.	Dependency risks: water availability, temperature, bushfire, soil quality, fertilizer, energy. Impact risks: bushfire, soil quality.
	Other air emissions (impact)	Other air emissions are priced at higher levels in future, or limited by regulations.	Forest establishment, management, and harvesting >> Changes in particulates and VOCs in the atmosphere >> Health effects, social concern and changes in regulation >> Increased costs.	Dependency risks: bushfires. Impact risks: bushfires.

Table 3 Evidence for the financial materiality of natural capital dependencies for Australian forestry

The materiality scores are given by the icons highlighted in red (high), orange (moderate) and green (low). For softwood plantations, hardwood plantations, and native forest

Risk Topic	Evidence for degree of the dependency	Confidence	Evidence for severity of threat	Confidence
Water availability (dependency)	Water availability is a critical determinant of tree growth [22-25], survival [26, 27], and wood quality [28]. There is strong correlation between leaf area index and annual precipitation [22] (and long-term rainfall [23, 25, 29]), which is in turn correlated with net primary productivity. Episodic reduced water availability (drought) is a threat to forest productivity and mortality [30-32]. New plantations may be unable to obtain or afford water allocations in water-stressed areas [33].	Well established	Rainfall is already declining in some plantation areas in Australia, leading to increased water stress [34]. Future projections are subject to uncertainty, but reductions in rainfall are projected for much of southern Australia [35]. Droughts are projected to increase in both intensity and frequency [36]. Groundwater availability also faces threats from reduced recharge due to the combined effects of increasing temperature and reduced precipitation [37, 38]. The long rotations for softwood and native forests (compared to Eucalyptus hardwood plantations) mean they are more exposed to both change in average rainfall and drought [39-42].	Well established
Temperature (dependency)	Common plantation tree species are grown at and tolerant of broad temperature ranges [43, 44]. However, mean temperatures do influence where plantations can be grown economically [45-47]. Productivity, survival and wood properties are all affected by heatwaves and hot days (although there is uncertainty in species-specific responses) [31, 42, 48-50]. In addition, cold temperature extremes (frost) can also affect tree growth and survival [51].	Well established	There is very high confidence that temperatures will increase in the future. Damaging heatwaves are likely to become more frequent and severe, with increases in very hot days [35]. Increases in dry summers and heatwaves may exacerbate heat stress in trees [52-54]. For cold temperature extremes, fewer frosts are projected. However, there is also evidence that warmer winter temperatures can reduce frost hardening in trees [51], and increasing atmospheric CO_2 may also increase frost sensitivity in eucalypts [55].	Well established
Bushfires (dependency)	Bushfires are one of the most frequent natural hazards in Australia [56]. Bushfires can affect wood volume, quality and saleability due to fire damage [57]. The type of forest and severity of bushfires determines the recovery or regeneration actions, and their associated cost [58]. In general, plantations damaged by fire must be cleared completely in order to be re-planted (thus incurring both clearing and re-planting costs). Native fire-tolerant forests can usually regenerate naturally [59] but in higher intensity fires even fire-tolerant species may die [58].	Well established	High fire risk days have increased and are projected to increase further in the future [35, 60, 61]. There has been a lengthening of the fire season, particularly in southern and eastern regions, and this is projected to lengthen further [62-66]. Fire regime changes from climate change could also interact with biodiversity affecting forest functioning. Transitions to alternative vegetation states/structures could also result in a positive flammability feedback [67-69].	Well established
Storms and floods (dependency)	Storms and floods are a major cause of forest loss around the world [70]. They lead to reduced productivity and cause damage and tree mortality. The susceptibility of trees is determined not just by weather conditions but also the forest structure, tree characteristics, and landscape characteristics [71-73]. For native forestry, the wind risk under clearfelling regimes is generally lower, however, this risk is increasing as aggregated variable retention regimes become more common [72, 74].	Well established	There is considerable uncertainty around future frequency, severity and duration of storms and floods and how this will impact forestry. Risks are likely to vary regionally, and also by storm type [75]. There is some evidence that an increasing proportion of rainfall is coming from heavy-rainfall events, with an increase in short-duration extreme rainfall and flash flooding [35]. Historical average wind speeds have shown evidence of a reduction over land since the 1980s (a process known as stilling [76, 77]), however, recent evidence suggests this trend may have reversed [78]. Increased productivity under climate change may lead to increases in wind damage [79, 80] since increased tree height:diameter ratios are associated with increased vulnerability to wind damage [81, 82].	Unresolved
Soil quality (dependency)	Soil underpins all forest productivity. It is involved in the supply of water and nutrients required for forest growth, and soil biodiversity plays an important role in mediating soil nutrient and carbon cycles [83-86].	Well established	Forest operations are an important factor in soil quality [87, 88] and soil quality changes can either be magnified or mitigated by management activities [84, 85]. Climate change may also affect soil quality, for example, through the interaction between soil organic carbon and temperature [89-93]. Soil quality is also linked to indirect effects including pest and disease outbreaks, fire, vegetation growth and species composition [94]. Future changes to soil quality are likely to be location specific and occur over various timescales.	Unresolved
Fertiliser use (dependency)	Fertiliser is generally not used in native forests [95], but is important for some plantations (particularly hardwood) to promote productivity [96] and can increase profits when applied at mid-to-late rotation [95]. Fertiliser use depends on biophysical factors (nutritional deficiencies in the soil) and economic factors [97]. While fertiliser increases the volume of wood there are concerns that the faster tree growth rate can reduce wood quality [98, 99]. Typical application rates are low and generally fertiliser costs are only a small percentage of total forestry costs [95].	Established but incomplete	Changes in fertiliser prices can affect business profitability, as well as affecting fertiliser application decisions, and thus productivity. Plantation forestry is vulnerable to fertiliser price shocks. However, the timing of some mid-rotation applications can be flexible, providing more resilience to price shocks compared to agriculture [95]. The price of fertiliser may be more relevant to economic margins in pulpwood plantations, and less significant in plantations grown for higher value products [95].	Inconclusive

Table 3 (continued)

Biodiversity (dependency)	Biodiversity contributes to forestry productivity in a number of ways but there is uncertainty in isolating and quantifying specific effects. Natural enemies of pests are important for controlling pest populations. While effective insecticides are available it is an additional business cost and the use of such insecticides is discouraged under FSC certification and can be toxic to aquatic fauna and socially unacceptable [100-104]. Soil biota contribute to nutrient cycling and plant health [105-107] and mycorrhizae (symbiotic fungus-root associations) are associated with strong growth gains - improving nutrient and water uptake [108-110]. Pollinators play an essential role in wild seed production for native forestry and seed orchards for hardwood plantations (although manual pollination is now widely practised for *E. globulus*) [111].	Established but incomplete	The uncertainty regarding the future impacts of climate change on biodiversity services makes this a moderate risk. For example, the rate of decomposition could slow in warmer and drier conditions [105] and the effectiveness of natural enemies in controlling pests could decrease if pest distributions shift into regions outside the distributions of their natural enemies [43]. Changes in regulation or insecticide resistance could also increase reliance on populations of natural enemies of pests. Climate change is affecting both the timing of phenology and the spatial distribution of many species. This could potentially reduce access to quality seed [112], alter mycorrhizal associations or affect the landcover and vegetation composition in native forests.	Unresolved
Weeds (dependency)	The presence of weeds can increase the costs of plantation establishment and management [113], and affect the abundance and diversity of native vegetation [114]. Weeds compete for light, water and nutrients, and reduce forestry production [115]. In plantations, controlling competition from weeds during early establishment has been shown to significantly improve growth and yield [116-119]. Weed management is often largely undertaken prior to tree planting and can be chemical (herbicides) or non-chemical (cultivation, slashing, burning and grazing). The techniques for weed management are well understood and costs are only a small proportion of total expenditure.	Well established	Climate change may affect the distribution of weeds, with some expected to expand while others will retract, depending on individual species' responses to climatic factors [120]. In southern Australia, the projected increase in temperature and decrease in rainfall will potentially allow for the expansion of weed species currently restricted to the tropical north [121, 122]. Changes in the frequency of extreme events, such as fires, droughts or storms, can also provide the opportunity for weeds to invade and establish [122]. Herbicide resistance and reduced herbicide efficacy are additional threats to future plantation productivity [123].	Unresolved
Pests and diseases (dependency)	Pest and disease damage on growth and survival of native and non-native forestry species is well documented, and the financial losses can be substantial [124-128]. Pathogen infestations can result in tree mortality as well as lost production. For example, the fungal pathogen Myrtle rust is now widespread across Australia [129]. Plantations can be more vulnerable to pests and diseases due to the low genetic diversity of clones and hybrids typically used [130]. Insects and fungi that are generally found in low numbers in native forests may become pests in eucalypt plantations [131, 132]. Additionally, the strong expectation of financial returns from plantations may lead to a lower tolerance to losses caused by pests and diseases.	Well established	Future changes in temperature, precipitation, and relative humidity may affect pest and pathogen abundance and distribution, either directly [133] or indirectly through physiological changes in the host, changes in natural enemies, competitors, and stress factors (e.g. drought) [134, 135]. There is uncertainty in the specific effects but generally, warmer annual mean temperatures are expected to increase the number of pest generations per year and the length of the damage season, as well as reducing winter mortality [136, 137]. Increasing winter temperatures are expected to facilitate range expansions of pests to higher altitudes and latitudes [138]. More frequent and severe droughts are also expected to increase pest and disease damage [139-141]. However, extreme high temperatures may also reduce survival and growth of insect and fungal species if their thermal limits are exceeded [138]. The risk from exotic pests is seen to be increasing, despite international regulations and biosecurity programs [142, 143].	Unresolved
Energy (dependency)	Forestry operations depend on fuel and energy use and this can be a substantial expense associated with harvesting [144] as well as log haulage. Diesel is the biggest energy input to forestry operations [145].	Well established	Poor energy efficiency relative to competitors could mean some forestry enterprises are unable to compete or are less attractive to investors looking for social and environmental impacts [146]. Fluctuating energy prices can affect business costs and profitability. However, there appears to be little correlation between fuel prices and the price of wood fibre, with studies showing that the price of wood products is dominated by supply and demand of the products rather than fuel price [147].	Inconclusive

forestry enterprise has on natural capital or ecosystem services, and that which addresses the severity of threats/consequences currently and in the future (as per the method shown in Fig. 2). Separate financial materiality assessments were developed for softwood plantations, hardwood plantations and native forest and are represented in the tables with the coloured icons.

Discussion

At a global level, forestry is known to have highly significant impacts and dependencies on natural capital, which can create direct risks for forestry enterprises and indirect risks for their investors, as well as for society more generally. There

Table 4 Evidence for the financial materiality of natural capital impacts for Australian forestry

The materiality scores are given by the icons highlighted in red (high), orange (moderate) and green (low). For softwood plantations, , hardwood plantations and native forest

Risk Topic	Evidence for degree of impact	Confidence	Evidence for severity of consequences to the business	Confidence
Water use (impact)	All forests use water during growth. This water is then not available for groundwater recharge and/or surface water flows, and therefore diverted from other ecosystem uses and downstream users [148]. Afforestation can affect catchment water availability [149-153]. A global systematic review found that in 80% of the studies the impact of afforestation on water yield was negative [153]. Impacts are more significant in water-stressed catchments or catchments where water is already highly allocated [154]. Afforestation in upper catchments can also provide benefits downstream through reduced peak flows and flooding frequency [153].	Well established	In some locations, new or expanded plantations might be unable to obtain regulatory approval to proceed, or face higher costs in the form of water rights, however, it is only likely to apply in water-stressed catchments [155, 156]. Climate change impacts on rainfall and increased demand from other water users may increase water stress and the likelihood of increased regulation or social concern [157-159].	Established but incomplete
Water quality (impact)	Forestry activities (preparation, harvesting, burning and the construction of roads, landings, bridges, culverts, and stream crossings) can lead to increases in turbidity and suspended solids in watercourses [160, 161]. The magnitude of any potential impact is dependent on a number of factors such as the slope and soil texture, as well as the type and techniques used in construction of roads etc. [162, 163]. Chemicals (fertilisers, herbicides and pesticides) can leach and leak into watercourses. There is a general consensus that this is associated with only short term increases in concentrations and that longer-term risks to water quality are considered small [161, 164].	Well established	Current regulations promote the protection of water quality by minimising the disturbance to watercourses and riparian zones [165]. Nevertheless, there are some ongoing community concerns with regard to forestry's impact on water quality [162]. Substantial changes to regulation are currently considered unlikely, meaning the regulatory compliance costs are known and it reduces the risk of any future increases.	Well established
Bushfires (impact)	Any forestry burning operation runs the risk of escaping control. The likelihood of fire escaping and severity of any fire will depend on fuel properties of the unburnt forest (including its size and age), its proximity to the burn boundary, the weather conditions and any response to suppress the fire [166]. Machinery-started fires are a moderate risk for plantations due to the year-round operations, including in the summer months. Prescribed burning is not used in established plantations but there may be some use of fire during site preparation or following harvesting to burn slash. Fire plays an important role in native forest management. It is used to create a favourable seedbed following logging, to achieve biodiversity outcomes and as part of fuel reduction burns [167, 168]. The more frequent and extensive use of fire in native forests means the risks of escape are higher.	Well established	Liability has been legally established for fires deliberately lit and then allowed to escape, regardless of the purpose for which the fire was lit [169]. Therefore, forest landowners and managers may face the risk of having to financially compensate neighbours for escaped fire from activities such as prescribed burning or land clearing, however, there is uncertainty about the extent of liability [170]. Liability for failing to reduce fuel loads, and so possibly contributing to fire spreading from one property to another, is theoretically possible, but would be legally difficult to establish and is not something that has precedent [169]. There is evidence of community concern regarding forestry estates and the perception of increased fire risk, particularly close to urban areas, which may lead to restrictions on the timing of forestry activities [171]. Financial consequences from escaped burns are uncertain but potentially very large. However, fire and fuel management practices and regulation, as well as the existence of public liability insurance, mitigates this risk.	Unresolved
Soil quality (impact)	Forestry operations can have significant impacts on soil quality. Forestry activities cause physical disruption or compaction of forest soil (e.g. establishment of roads and use of heavy harvesting machinery) [84]. This can lead to ponding, waterlogging and erosion [85]. Forestry operations can also increase soil erosion by loosening the soil and by removing groundcover, which exposes the soil. Management activities can affect soil carbon and nitrogen [172, 173], site residues management post-harvest or pre-establishment can have significant impacts [86, 174]. Chemicals used to control weeds and pests can accumulate in the soil, influencing soil biota such as earthworm populations [175].	Well established	The consequences of soil quality degradation can be directly felt by forestry enterprises through impacts on tree growth and productivity, or indirectly through regulation or social concern. Soil management practices to minimise impacts (or repair damage) are well known and embedded in existing regulations and certification frameworks [165, 176]. It is possible that more restrictive or costly regulation or voluntary certification schemes could be imposed in the future. However, the availability of well-understood mitigation options reduces the potential financial consequences of this risk.	Well established
Contamination and waste (impact)	Overall, there is little evidence of significant land contamination. A study found that three bio-lubricants commonly used in forestry posed little risk to the environment [177]. Some evidence exists that shows that the leakage of oils used in chainsaws could alter soil physical properties by decreasing air-filled porosity and increasing water repellence of the soil [178].	Established but incomplete	Australian forestry enterprises have legal obligations to manage contamination that is either pre-existing or caused through their activities. Voluntary certification standards also require forest managers to ensure that waste materials are disposed of in an environmentally appropriate manner and to demonstrate that chemicals and waste are not discharged to soil [176]. The costs of meeting these obligations are known and unlikely to change substantially in the future.	Well established
Biodiversity (impact)	Native forestry can alter forest age structure by increasing the abundance of younger forest and hence reducing the abundance of mature habitat that is important for species that require nesting hollows, feed on flowers and fruits, or forage on bark [179-184]. Clearfelling regimes have been shown to impact species	Well established	Community perceptions of forest management and issues around social licence to operate are complex and multifaceted, and can change over time [191-193]. There exists considerable community concern regarding native forestry activities and community pressure could further restrict forestry activities. There is also concern regarding the impacts of plantation	Well established

Table 4 (continued)

	composition and abundance [185] with studies showing that aggregated retention silviculture sustained greater numbers of mature forest bird communities and beetle populations [183, 184]. Plantation harvesting practices also remove habitat and can affect landscape connectivity, while site preparation can damage soil structure, organic matter and soil biota [186]. However, most plantations in Australia are established on ex-agricultural or existing plantation land, which minimises some of the negative impacts [186-188]. Plantation forests can also play a role in protecting forest remnants in agricultural landscapes from biodiversity declines triggered by edge-effects [189] and contribute to catchment-level tree cover needed to maintain healthy aquatic ecosystems [190].		harvesting on biodiversity [191, 193]. There is the potential for this to increase as awareness of the biodiversity present grows and as certain species become more reliant on the habitat provided by plantations, due to other land use changes or climate change effects. Special regulatory prescriptions can be activated where threatened species or communities are found to be present in forests, which may prohibit or restrict forestry activities in certain areas [194].	
Weeds (impact)	Forestry operations can cause weed spread and establishment through wildlings associated with softwood plantations [195, 196] and to a lesser extent hardwood species [197]. Hardwood species can also contribute to genetic pollution of adjacent native stands [198]. Forestry management also contributes to weed spread through accidental dispersal of weeds by humans, vehicles and equipment [199, 200]. Soil disturbance associated with roading, site establishment and harvesting activities also provides conditions for weeds to propagate [201].	Well established	Concerns exist about weed infestations and much attention in Australia has focused on movement of weeds into national parks, conservation areas and agricultural land [202, 203]. Community concerns about weed incursions into neighbouring forested areas and waterways also exist and the resulting impact to biodiversity [204]. Such concern has the potential to lead to further regulatory restrictions or to affect social licence to operate. However, the consequences for businesses are unlikely to increase significantly, as weed management techniques are well developed and costs known.	Well established
Pests and diseases (impact)	Forestry operations can influence the incidence of pests and diseases in adjacent forests through dispersion (the movement of vehicles, machinery and people between sites). This has been linked to the spread of soil-borne pathogens such as *Phytophthora cinnamomi* [205]. Plantations of exotic species can also facilitate the introduction of non-native pests such as insects [206]. Forest disturbance can artificially elevate the abundance or distribution of pests or pathogens, such as Myrtle wilt [207]. Monoculture plantations can also increase pest and disease populations by providing a uniform source of food and optimal conditions [208].	Well established	Pests and diseases can be a concern for adjacent landowners and communities, who might be concerned that infestations may develop in high value conservation areas or on private land in urban areas [205, 209]. There is the potential for expanded regulation or further certification requirements to protect adjacent areas. This would have financial consequences for forestry businesses, but the probability of substantial change is considered to be low.	Established but incomplete
Greenhouse gas emissions (impact)	Forestry operations contribute to greenhouse gases through land use change, site preparation and establishment, management, and harvesting activities. Log haulage and harvesting are typically the greatest contributors to emissions per unit wood production in plantations and native forestry [210]. Management activities such (e.g. fertiliser) [95, 211] and fire can also contribute to emissions [210, 212, 213]. Direct operational emissions for Australian softwood production are low compared with native forestry and international comparisons [210], and almost two-thirds of production goes towards longer-lived wood products. For hardwoods in Australia, most production currently goes towards short-lived fibre products. Forest loss and degradation is recognised as a major source of emissions. However, conversion of native forests to plantations is now rare in Australia.	Well established	There is currently no direct carbon pricing applied to forestry operational emissions in Australia, with the exception of projects receiving funding for net emission reductions/removals from the Commonwealth Emissions Reduction Fund, which must deduct any operational emissions from calculated net emission reductions/removals. However, there is a risk that greenhouse gas emissions could be further regulated or priced in the future. This risk is offset by the potential for income generation through carbon sequestration schemes.	Unresolved
Other air emissions (impact)	Fire is routinely used in native forests in Australia to reduce fire hazard, and for preparation of seedbeds, it is also sometimes used to remove harvest residue [168, 214]. In addition, both plantations and native forests are exposed to uncontrolled bushfires. The smoke from both controlled and uncontrolled burns can be a public health concern, particularly when burns are close to populated areas [215, 216]. Forests can also contribute to the formation of ozone (a problem in metropolitan areas) through emissions of volatile organic compounds (VOCs) [217-219].	Well established	Considerable community concern about smoke exists [220, 221] and the impacts of burning practices in regions where fire is routinely used as a management tool [222]. Currently, there are regulatory restrictions on the timing and type of burning to minimise the impact on surrounding areas, however, the business costs of these restrictions are relatively small and unlikely to increase substantially in the future. There is a risk of restrictions being tightened in future. The consequences for businesses are likely to be negative, but the magnitude of these consequences is currently uncertain.	Established but incomplete

is a need for improved understanding of natural capital risks to enable better decision-making by forestry enterprises, as well as their lenders and investors, regulators and other stakeholders. Assessing natural capital risks offers a range of benefits to enterprises, from improved risk management to the ability to access new financial opportunities [4], but one of the biggest opportunities is the ability to communicate risk information in a consistent and comparable way to stakeholders. Reporting nature-related risks is not yet mandatory in most jurisdictions, but there are growing expectations that this will become mainstream practice in future [223], following the recommendations of the TCFD to encourage the disclosure of climate-related risks [16] and the recent establishment of an international Taskforce on Nature-Related Risk Disclosure (TFND) [224].

A first step towards detailed understanding of natural capital risks at individual estate level is to conduct a materiality assessment at a broader scale, in order to identify key risk areas of likely relevance, as the potential scope of natural capital dependencies and impacts for any industry is vast, with hundreds of different ecosystem services being identified in international classifications [225]. The financial materiality assessment presented here narrows down the potential scope to twenty key risk areas of relevance to Australian forestry, of which only seven to nine have been assessed as highly material for each industry sub-sector. This means that forestry enterprises, investors and other stakeholders can focus their available resources on more cost-effective assessment and management of a small set of highly material risks, which can be gradually expanded over time, if necessary and practicable, to include lower materiality risks.

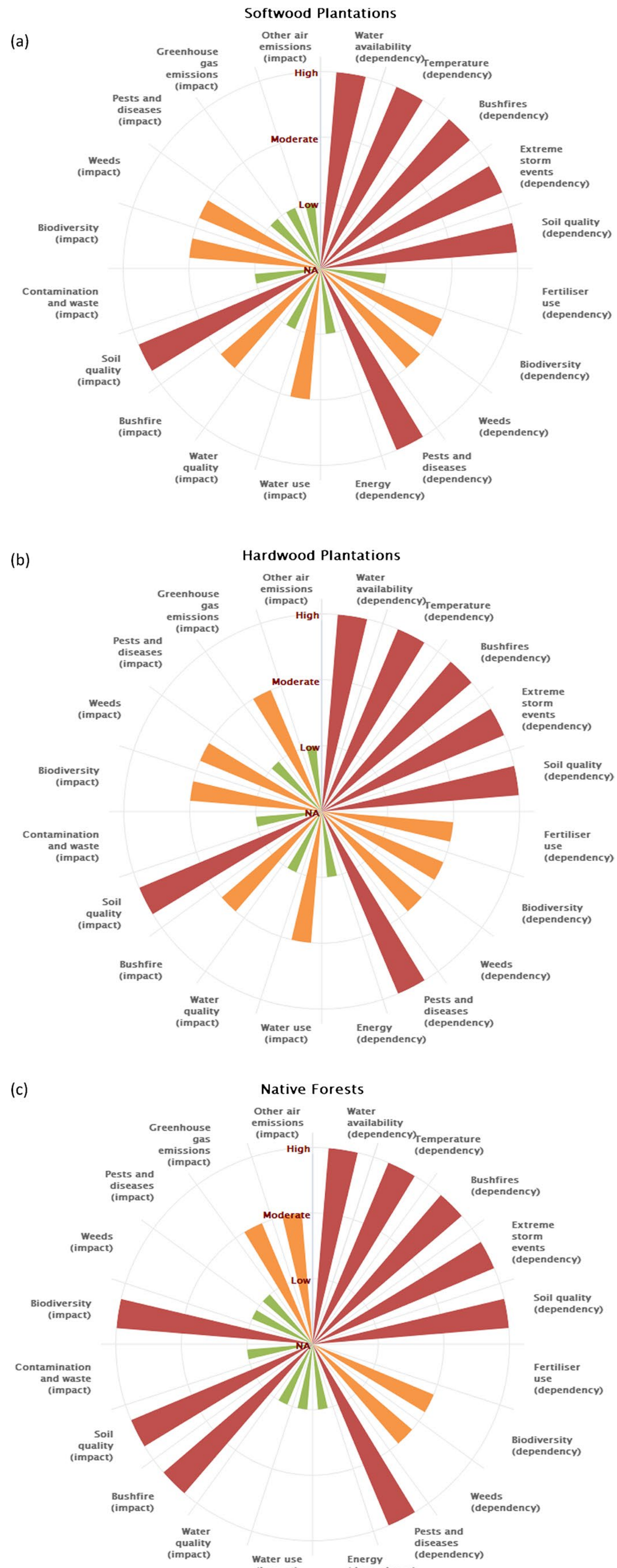
The most financially material risks for Australian forestry were associated with water availability, temperature, bushfire, storms and floods, soil quality and pests and diseases (for all sub-sectors), and biodiversity (for native forests). All of these highly material risks arise from natural capital dependencies, apart from biodiversity, which was an impact risk for native forests only, and bushfire and soil quality, which were highly material in terms of both impact and dependency risks (noting that bushfire impact is only assessed as highly material for native forests) (Tables 3 and 4, with overall materiality scores illustrated in Fig. 4). For nearly all of these, there was high confidence in the assessments based on well-established principles and processes described in the literature, for both the degree of the dependency/impact and the severity of threats/consequences (with the exception of the severity of the threat for storms and floods, soil quality and pests and diseases and the severity of consequences for bushfire impact, which were all assessed as unresolved and thus are suitable targets for further research). Overall, there was relatively high confidence in the evidence for degree of dependency/impact (80%/90% well established) and lower confidence in the evidence for severity of threat/consequences (30%/50% well established). The lower confidence for the severity of threats relates to the uncertainty about the future threats from climate change and for the severity of the consequences relates to there being limited evidence to link to specific financial consequences for forestry enterprises.

There is a reasonably high level of overall consistency in the materiality scores between the different sub-sectors in Australian forestry. However, there are a few important differences (Fig. 4). The main differences can be observed by comparing native forestry with plantations. For example, biodiversity is assessed as a more material impact risk from native forestry (high) compared to plantations (moderate) due to the potentially significant impact of clearfelling harvesting regimes in native forestry and the considerable community concern regarding impacts on threatened species. While plantations can also affect biodiversity, many plantation forests are now established on ex-agricultural or existing plantation land in Australia, and so the industry-level materiality of the risk is lower. Bushfire impacts are also assessed as a more material risk for native forestry (high) compared to plantations (moderate) due to prescribed burning being more common for native eucalyptus forests, and the use of fire for preparing seed beds in native forestry. Similarly, other air emissions are assessed as more material for native forests (moderate) due to the greater use of prescribed burning. Finally, water use is assessed as a lower risk for native forestry (low) compared to plantations (moderate) due to native forestry generally being a seen as a continuation of existing land use, and so not substantially altering the available water for users downstream.

Softwood and hardwood plantations have broadly similar risks. Greenhouse gas emissions are assessed as a higher materiality risk for hardwood plantations (moderate) due to the higher proportion of wood that goes towards short-lived fibre products. Fertilizer as a dependency risk is also assessed as higher risk for hardwood plantations (moderate) due to the greater use and reliance on fertilizer.

The limitations of this assessment include the fact that the results presented here apply only to the whole of industry level in Australia, at the current time. Location-specific assessments may differ by geographic location both within Australia and globally. At the forestry estate level, it could also be the case that assessments may differ within the individual estate due to the large geographical extent of many forest estates. The methodology used here seeks to assess each topic separately, however, we acknowledge that risks rarely occur in isolation and understanding the interactions and interlinkages will be important in further detailed analyses. It is also important to note that the financial materiality assessment presented here does not take into account the application of risk mitigation actions beyond standard industry practices (for example, those stipulated in industry codes of practice). Options for further mitigation are identified in [21], and can potentially be used to modify the materiality assessments at enterprise scale. As such the results presented here relate to natural capital risks that are potentially financially material for forestry enterprises and should not be interpreted as estimates of the actual risk.

Fig. 4 Financial materiality assessment scores for dependency and impact risks for Australian forestry – softwood plantations (**a**), hardwood plantations (**b**) and native forestry (**c**). The size of the bars (and corresponding colour) represents the materiality score associated with each risk category, such that low materiality is represented with a short bar (close to the centre) and high materiality is represented by a long bar (which extends to the edge of the figure)



Conclusions

Two key lessons emerge from our review: first, the most financially material risks for Australian forestry are largely associated with natural capital dependencies; and second, nearly all of the most material risks are likely to be exacerbated by climate change. In Australia, the management of forestry natural capital impacts is already highly regulated, with mitigation strategies in place. Dependency risks, on the other hand, are less well recognized, and more difficult to manage than impact risks. Greater awareness of these dependency risks is a first step towards taking more targeted action to mitigate and manage these risks. Climate change is identified as an underlying driver of environmental change affecting the most material dependencies, such as water availability, temperature, bushfires, storms and floods, soil quality and pests and diseases. Understanding how dependency risks will change in the future under a changing climate and how to mitigate those risks is a key challenge for the forestry industry.

Our framework and industry-level financial materiality assessment provides a guide to future assessments for individual forest estates. The use of frameworks and guidelines like this can (a) increase the comparability and credibility of assessments, (b) provide a systematic way for enterprises to identify what it is important to report against, and to manage in their operations, and (c) put the industry in a better position to disclose natural capital risks to markets and potential investors. Further research that builds on this paper will be required to enable individual businesses to undertake natural capital risk assessments. A key next step is to identify suitable data and indicators to address the most material risks. Those indicators and data sources should adequately represent each risk and need to be feasible and cost-effective to measure and collate. Ideally, they should be harmonized across the industry and meet the needs of all relevant stakeholders. Further research to identify data sources and indicators would help reduce transaction costs for businesses and promote trust in the reliability, consistency and comparability of reported information.

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Declarations

Conflict of Interest Greg Smith, Francisco Ascui, Anthony O'Grady and Libby Pinkard declare they have no conflict of interest.

Human and Animal Rights All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

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