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How is Australia Adapting to Climate Change Based on a Systematic Review?

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Abstract

We develop and apply a systematic literature review methodology to identify and characterize the ways in which the peer-reviewed literature depicts how climate change adaptation is occurring in Australia. We reviewed the peer-reviewed, English-language literature between January 2005 and January 2018 for examples of documented adaptation actions. Our results challenge previous assumptions that adaptation action is not happening in Australia and describes adaptation processes that are underway. For the most part, actions can be described as preliminary or groundwork, with a particular focus on documenting stakeholder perspectives on climate change and adaptation, and modelling or scenario planning in the coastal zone, agriculture and health sectors. Where concrete adaptations are reported, they are usually in the agricultural sector and are most common in the Murray-Darling Basin, Australia's food basket. The findings of the review advance our understanding of adaptation to climate change as a process and the need to consider different stages in the process when tracking adaptation.

Keywords: adaptation; adaptive capacity; adaptation tracking; climate change; systematic review; vulnerability; developed nation; Australia

1. Introduction

In Australia, documented climatic changes include rising temperatures, changing rainfall patterns, more extreme events (heat waves, bushfires, flooding, storm events), increasing ocean temperature, and sea-level rise (Head et al. 2014). These changes, together with other anthropogenic drivers of environmental change (i.e. resource development, population increase), have already negatively affected terrestrial, freshwater and marine ecosystems such as the Great Barrier Reef (Ainsworth et al. 2016), compromised agricultural production in some regions (Asseng and Pannell 2013), and have negatively affected human health (Beggs and Bennett 2011). Climate models project that these changes will continue, and likely accelerate into the future, with further effects on ecosystems and people (IPCC 2013). Notwithstanding the importance of mitigation initiatives, adaptation is desperately needed if the negative impacts are to be moderated and opportunities captured (Reisinger 2014).

In light of the urgency for adaptation, efforts to track adaptation initiatives have increased in recent years (Biesbroek et al. 2010). Some researchers have mapped the current state of adaptation in particular places and sectors to better understand adaptation processes and identify knowledge and resource needs. For example, researchers have completed systematic reviews of the peer-reviewed literature to characterize adaptation actions (herein referred to as concrete[1] actions) in the Canadian Arctic (Ford and Pearce 2010), among developed nations (Ford et al. 2011), and globally (Berrang-Ford et al. 2011). In their review of observed climate change adaptations in developed nations reported in the peer-reviewed literature, Ford et al. (2011) found few examples of concrete adaptations underway in Australia, and labelled

[1] Adaptation/concrete actions: "tangible steps taken to alter institutions, policies, programs, built environments, or mandates in response to experienced or predicted risks of climate change" (Lesnikowski et al. 2013, p. 1155).

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Australia a laggard in climate change adaptation. We test the hypothesis that Australia is a laggard in climate change adaptation using a systematic review of the peer-reviewed literature and a definition of adaptation that includes both groundwork[2] and concrete actions (Lesnikowski et al. 2013). The findings of this review are intended to provide a proxy of the state of adaptation in Australia from the perspective of the peer-reviewed literature.

2. Climate change adaptation in Australia

Aboriginal and Torres Strait Islander peoples have a long history of coping with and adapting to changing environmental conditions including recent climate change (Green et al. 2010b; Prober et al. 2011). Formal adaptation to climate change among non-Indigenous people in Australia, however, is relatively new. Adaptation to climate change was first recognized as a priority by the Australian government in 2004 with the announcement of a budget for a National Climate Change Adaptation Programme. The programme aimed to help prepare industries, communities, and state and local governments for the impacts of climate change (The Allen Consulting Group 2005). Later in 2006, the Council of Australian Governments requested the development of a National Adaptation Framework as part of its Plan of Collaborative Action on Climate Change. The Framework described a collaboration agenda for governments at various levels to address climate change impacts and generate information for effective adaptation (Australian Government 2007). In 2007, the Climate Adaptation Flagship was established under the Commonwealth Scientific Industry and Research Organization (CSIRO), to provide practical and effective adaptation options for policy

[2] Groundwork actions: "preliminary steps taken toward adaptation that inform and prepare countries to implement adaptations, but do not themselves constitute changes in policy, programs, or delivery of services" (Lesnikowski et al. 2013, p. 1155).

makers, industries and communities (CSIRO 2015). As a part of the National Climate Change Adaptation Programme, the Australian Government established the National Climate Change Adaptation Research Facility (NCCARF) in 2008. The NCCARF brings together Australian researchers to address priority questions about climate change impacts and adaptation, and to communicate this knowledge to decision-makers in order to facilitate more effective adaptation at multiple scales (Australian Government 2015). The NCCARF originally received five years of funding worth $50 million (AUS) for phase 1 (2008-2013), $30 million of which funded approximately 100 research projects and 8 networks that focused on building capacity (NCCARF 2014). Phase 2 (2014-2017) received funding of $8.8 million (AUS) and focused primarily on capacity development and support, particularly by ensuring that research materials from phase 1 were synthesized and accessible to decision-makers at the local level (NCCARF 2014).

Adaptation to climate change is also the focus of state, territory, and local governments, mostly within their environmental agendas and as part of their own climate change strategies (Fidelman et al. 2013). In Australia, the responsibility of adaptation planning is largely placed on municipal councils, reflecting the country's diverse geography and broad scope of potential climate change impacts and adaptations (Bradley et al. 2015). With that said, effective climate change adaptation requires a multi-governance approach in which each level of government has a shared responsibility (Nalau et al. 2015).

3. Methods

A systematic literature review was used to examine the ways in which the peer-reviewed literature depicts how climate change adaptation is occurring in Australia

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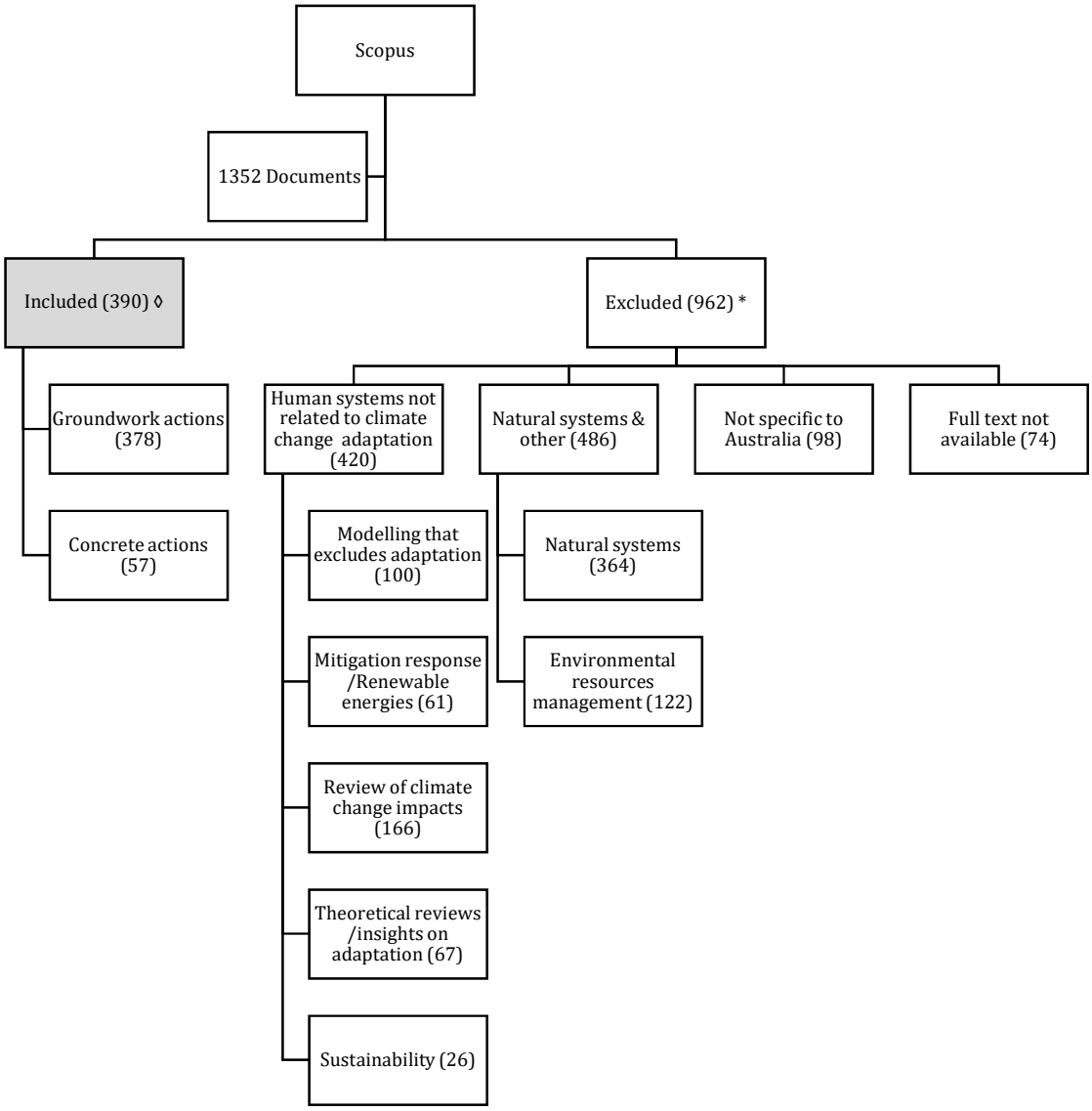
following methods described by Lesnikowski et al. (2013) for differentiating actions as groundwork and concrete. Systematic literature reviews respond to specific questions by using explicit and reproducible methods for selection and analysis. While this review approach is common in the health sciences, it has also gained traction in the climate change field as a way to characterize and keep track of the burgeoning body of literature (Berrang-Ford et al. 2015).

3.1 Document selection

A document search was performed in the Scopus database using the terms "*Adapt**" AND "*Climat* Change*" AND "*Australia**" in the title, keywords, and abstract fields. Scopus was selected due to its availability as one of the most current, powerful, comprehensive and widely used search engines for peer-reviewed literature (Falagas et al. 2008). The review focused on peer-reviewed literature reporting or discussing intentional human adaptation initiatives published between January 2005 and January 2018, reflecting the goal of characterizing how the peer-reviewed literature depicts how climate change adaptation is occurring in Australia. Documents that were not peer-reviewed, in languages other than English, outside of the search period, books and abstracts, and those where a full text copy was not available online were excluded. In total, the search retrieved 1352 documents (Figure 1 and supplementary materials, supplement B). The title and abstract of all retrieved documents were reviewed against set criteria to evaluate suitability for inclusion in the review (Tables 1 and 2).



◊Documents can discuss multiple adaptation actions (both types of action—groundwork and concrete)

*Documents can be classified within multiple exclusion categories. These groups are not mutually exclusive

Fig. 1 Summary of document selection

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Table 1 Inclusion and exclusion criteria for document selection

Inclusion	Exclusion
Phase 1: keyword search	
Articles Reviews Book chapters Conference papers English Jan 2005-Jan 2018 Full text available	Abstracts only Books Non-English Out of the timeframe Full text not available
Phase 2: title and abstract review (full text review when required for categorization)	
• Human systems undergoing adaptation initiatives • Groundwork actions: 1) Impact, risk, vulnerability and adaptive capacity assessments 2) Research on adaptation options 3) Conceptual tools 4) Stakeholder perspectives and networking opportunities 5) Recommendations for adaptation actions 6) Modelling that evaluates or/and suggests climate change adaptation 7) Economic analysis focused on adaptation 8) Policy and framework reviews that suggest adaptation • Concrete actions: tangible actions taking place as a response to climate change effects	• Natural and physical systems (plants, animals, soil, land, water, climate) • Human systems not including adaptation initiatives • Modelling that excludes adaptation • Mitigation actions • Renewable energies • Reviews of impacts • Theoretical reviews/insights on adaptation • Not specific to Australia

Table 2 Description of search criteria classification

Included	**Groundwork actions:** *1) Impact, risk, vulnerability and adaptive capacity assessments* Articles provide site or industry specific assessments on climate change impacts, risks, and vulnerabilities, as well as adaptive capacity. Articles suggest methodologies for the development of such assessments. *2) Research on adaptation options* Articles explore the different aspects, costs and benefits of adaptation options that are or could be implemented in Australia. *3) Conceptual tools* Articles provide conceptual tools like frameworks, guidelines, and theories to improve planning, implementation and/or management of adaptation initiatives. They discuss lessons on adaptation practice and explore the applicability of these for the Australian society and environment.

	4) Stakeholder perspectives and networking opportunities Studies focusing on identifying, discussing, and understanding stakeholder perspectives on climate change and their attitudes towards adaptation. *5) Recommendations for adaptation initiatives* Studies research potential improvements for current adaptation initiatives. *6) Modelling that evaluate or/and suggest climate change adaptation* Articles explore the effects and impacts of climate change in the different sectors of society as well as the role of adaptation initiatives in future scenarios. These articles emphasize, evaluate or/and suggest the need for specific adaptation actions based on the predictions obtained by the models and future scenarios analysis. *7) Economic analysis focused on adaptation* Articles provide economic analyses on adaptation actions that are occurring or could occur in Australia. These articles provide assessments on adaptation actions profitability and/or estimate the costs and benefits of these. *8) Policy and framework reviews that suggest adaptation* Articles suggesting the inclusion of aspects of climate change adaptation in existing policies and frameworks.
	Concrete adaptation actions: Tangible steps taken to alter institutions, policies, programs, built environment, or mandates in response to experienced or predicted risks of climate change.
Excluded	**Natural systems and other:** *Natural systems* Studies focusing on the effects of climate change on the biological (animal, plant) and physical (soil, land, water, and climate) systems only. Prehistoric climate papers and empirical studies examining crops focusing only on biology/ecology were included in this category. *Environmental resources management* Articles focusing on the management of natural systems and their provision of ecosystem services that do not make a specific reference on climate change adaptation.
	Human systems not related to climate change adaptation: *Mitigation response/ renewable energies* Articles focusing on mitigation strategies, the reduction of greenhouse gas emissions, energy efficiency and clean energy production. Articles focusing on increasing carbon sequestration. *Review of climate change impacts* Articles focusing on the effects and impacts of climate change for the different sectors of society (without the use of assessments). These articles identify adaptation as a need and justify it with the review of impacts but do not address specific adaptation actions. They suggest adaptation actions but lack further explanation and details on the way these should be implemented. *Theoretical reviews/ insights on adaptation* Literature and theoretical reviews or insights on climate change adaptation as a general practice. Reviews on some adaptive actions or aspects of climate change

	adaptation that do not specify the location and/or guidelines for their implementation. Reviews on barriers and challenges for implementation of climate change adaptation. Articles focusing on adaptation without enough information to answer the questionnaire. Articles examining current adaptation policies without making a contribution for improvement. *Sustainability* Articles focusing on programs, processes and ideas on sustainability without an explicit focus on climate change adaptation.

3.2 Document review

390 documents were retained for full review (see supplementary materials, supplement A). A questionnaire was applied to each document and focused on: general characteristics of the articles (year of publication, authorship, and category of adaptation initiatives); and nature of the adaptation initiative (groundwork or concrete actions, stimulus motivating the adaptation initiative, who or what is adapting, and the details of the adaptation initiatives). Once concrete and groundwork actions were separated, groundwork actions were grouped in 8 categories: 1) impact and vulnerability assessments, 2) research on adaptation options, 3) conceptual tools, 4) stakeholder perspectives and networking opportunities, 5) recommendations for adaptation actions, 6) modelling that evaluates or/and suggests climate change adaptation, 7) economic analysis focused on adaptation, and 8) policy and framework reviews that suggest adaptation.

4. Results

4.1 Reporting on adaptation is increasing

Reporting on adaptation in Australia in the peer-reviewed literature has increased over the past ten years, consistent with trends observed in other countries (Ford et al. 2014). In particular, there was a sharp increase in adaptation reporting

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observed from 2009 onwards, which may partially be explained by the establishment of the NCCARF in 2008 and the publication of project findings that followed (Fig. 2). The increase between 2009 and 2014 is followed by a peak and plateau from 2014 onwards, and slight dip in 2017. This may be partially linked to the beginning of phase 2 at the NCCARF in 2014, which involved less funding and a larger focus on network- and capacity-building, as well as the synthesis and accessibility of research materials, than the adaptation research programme (NCCARF 2014). Because the final Scopus search took place only 2 weeks into January 2018, it is difficult to determine whether the dip in 2017 is a signal of an overall down-turn in the amount of adaptation research being completed, reviewed and published in Australia, or if this number may be an anomaly or influenced by other factors (e.g. book chapters not yet available online or through Scopus).

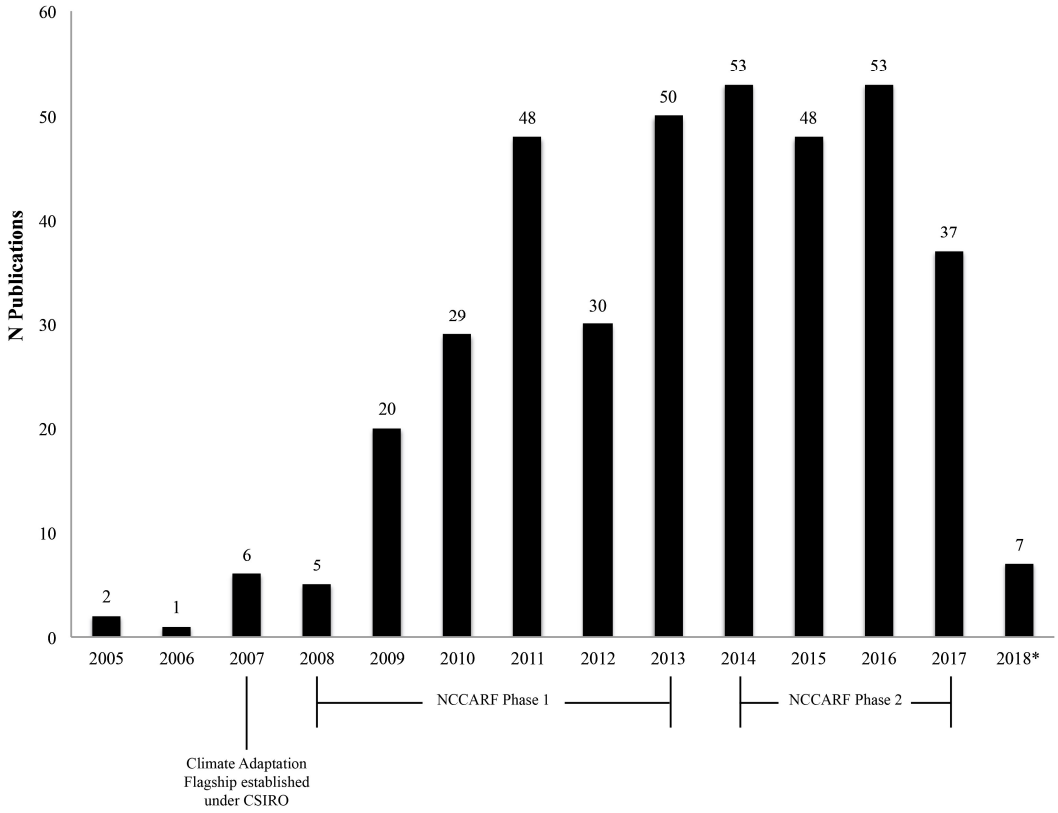

Fig. 2 Number of publications by year (*only includes two weeks of 2018).

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4.2 Adaptation initiatives primarily focus on groundwork adaptation actions

Reported adaptation initiatives are primarily composed of groundwork actions. Of the 390 documents included, 85% (n=333) report on groundwork actions alone, 12% (n=45) report on both groundwork and concrete actions, and only 3% (n=12) report on concrete actions alone. This finding is consistent with the dominant federal government narrative that climate change adaptation has focused on strengthening the science of climate change and addressing knowledge gaps in order to provide the foundations for effective adaptation policies and actions (Asseng and Pannell 2013). All eight of the groundwork categories are represented in reported groundwork actions, but there is a particular focus on understanding stakeholder perspectives on climate change and attitudes towards adaptation (category 4), modelling future climate change impacts and adaptation scenarios (category 6), assessing impacts, risk and adaptive capacity in different places, groups, or industries (category 1), and strengthening the science on which future climate predictions and impact assessments are based (categories 1 and 6) (Fig. 3).

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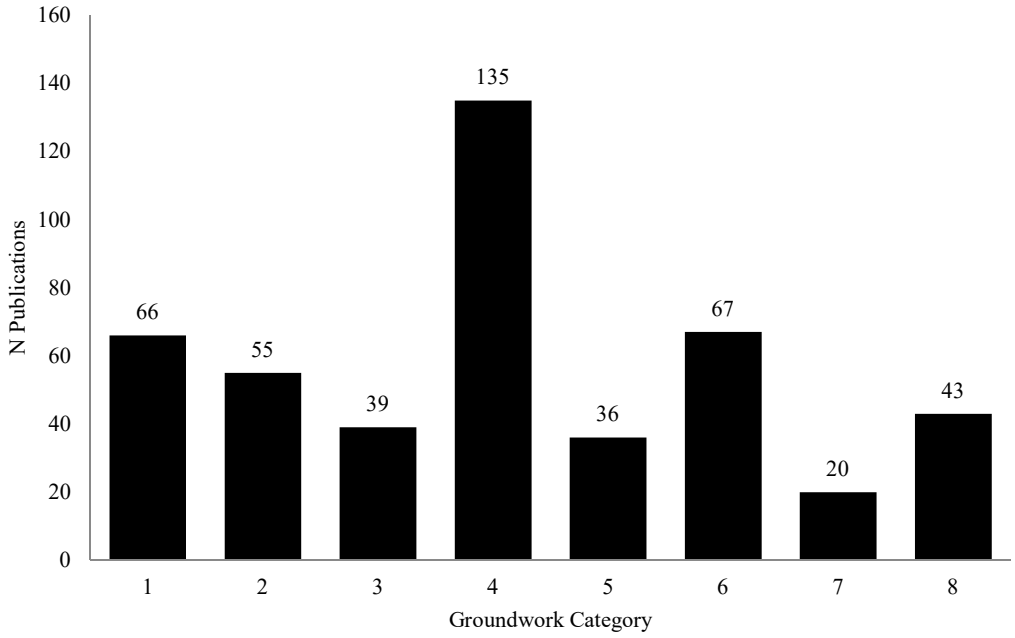

Fig. 3 Distribution of groundwork adaptation actions. Numbers 1 – 8 indicate groundwork categories: 1) Impact, risk, vulnerability and adaptive capacity assessments; 2) Research on adaptation options; 3) Conceptual tools; 4) Stakeholder perspectives and networking opportunities; 5) Recommendations for adaptation actions; 6) Modelling that evaluates or/and suggests climate change adaptation; 7) Economic analysis focused on adaptation; and 8) Policy and framework reviews that suggest adaptation.

Of the articles that report on groundwork adaptation actions, the most common focus is on documenting stakeholder perspectives on climate change and their attitudes towards adaptation (35%, n=135). Some of these articles seek to understand stakeholders' views on climate change, risk and adaptation (e.g. Ambrey et al. 2017), while others explore mechanisms to more effectively engage community members in climate change adaptation planning and implementation (e.g. Carmichael et al. 2017). Other studies aim to understand how adaptation is influenced by stakeholder perspectives on climate change, current socio-economic situations, attitudes towards change, and engagement in decision-making (e.g. Elrick-Barr et al. 2015). It is suggested that understanding stakeholder perspectives on climate change and their

attitudes towards adaptation will increase the likelihood that adaptation strategies will appeal to a broader range of stakeholders and enhance the likelihood of success (Buys et al. 2012).

The second most frequently documented groundwork adaptation action is scenario planning and/or modelling (17%, n=67). Scenario planning involves the visualization of future conditions and their possible consequences and effects, and modelling involves the representation of those futures through the use of mathematical equations (Flynn et al. 2018). Scenario planning and modelling are most often used as tools for assessing the uncertainty of long-term climate change and possible adaptation outcomes. In many instances in the literature, these tools are used to assess adaptation options in the agricultural sector (70%, n=47). This usually involves modelling yield production for different scenarios of crop diversification and management practices (e.g. tillage, forage and weed management) under various climate scenarios (e.g. Zheng et al. 2016). Freshwater management options (water trade) in terms of environmental and socio-economic impacts during extreme events (i.e. droughts) are also a key area of analysis within category 6 (18%, n=12) (e.g. Wheeler et al. 2014). Additionally, options to adapt infrastructure to deal with extreme events (i.e. cyclones and storms) have been modelled to assess costs-benefits and efficiency (e.g. Li and Stewart 2011). Twelve of the articles from category 6 also focus on modelling the economics of adaptation, which also accounts for 60% of category 7.

Articles that focus on impact, risk, vulnerability and/or adaptive capacity assessments (category 1) are the third most frequently reported groundwork action, making up 17% (n=66) of all included articles. Within this category the primary focus is identifying how climate change is affecting socio-ecological systems and adaptation options (e.g. Johnson and Welch 2016). Some of the studies in this category seek to

measure and quantify risk (e.g. Singh et al. 2017), while others aim to characterize how climate change is experienced and responded to in a specific sector (e.g. infrastructure, agriculture, fisheries, health) or among a group of people (e.g. Bradley et al. 2015). Several studies use integrated assessments that consider how socio-economic and cultural factors influence how people experience and respond to climate change (e.g. Bardsley and Wiseman 2012). Within category 1 there are also studies that seek to advance climate change adaptation research by developing frameworks for assessing climate change impacts and vulnerability (e.g. Chen et al. 2015). As a whole, the articles in category 1 have a strong emphasis on adaptation specifically, including adaptation to the health effects of climate change (e.g. Bowles 2015).

Between categories 2 (14%, n=55), 5 (9%, n=36), and 8 (11%, n=43) adaptation is primarily approached by reducing vulnerabilities and impacts through a focus on enhancing adaptive capacity. Several studies in these categories examine approaches to strengthen adaptive capacity through planning, natural resource management, and planning policy (e.g. Sheaves et a. 2016). There is also a particular focus on examining adaptation options and capacity building in response to the effects of climate change on urban areas (e.g. Isler et al. 2010) and agricultural production (e.g. Petrie et al. 2017), particularly through the lenses of freshwater availability and health (see sections 4.4 and 4.6). Common themes that emerge for facilitating adaptation include: i) the importance of integrating local observations and monitoring in adaptation planning (e.g. Green et al. 2010a); ii) the role and importance of local and Indigenous knowledge (IK) in adaptation (e.g. Leonard et al. 2013); iii) the need to consider non-climatic factors that influence adaptation including socio-economic and cultural factors (e.g. Mee et al. 2014); iv) the value of inter-disciplinary research and stakeholder participation in adaptation research and planning (e.g. Bardsley and Sweeney 2010) and v) the need for

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policies and governance to work across scales to support the proactive enhancement of adaptive capacity (e.g. Serrao-Neumann et al. 2016).

4.3 Reporting on adaptation is geographically focused on eastern Australia

Reported concrete adaptation actions are primarily from eastern Australia, with a concentration in New South Wales, Victoria, and Queensland. Of the 57 articles reporting concrete adaptation actions, 56% (n=32) concentrate on at least one of the three states, with 14% (n=8) reporting on concrete actions in two or all three states. The same is true for groundwork adaptation actions (Fig. 4). Of the 378 articles reporting groundwork adaptation actions, 40% (n=154) concentrate on at least one of these three states, with 16% (n=60) reporting on groundwork actions in two or all three states.

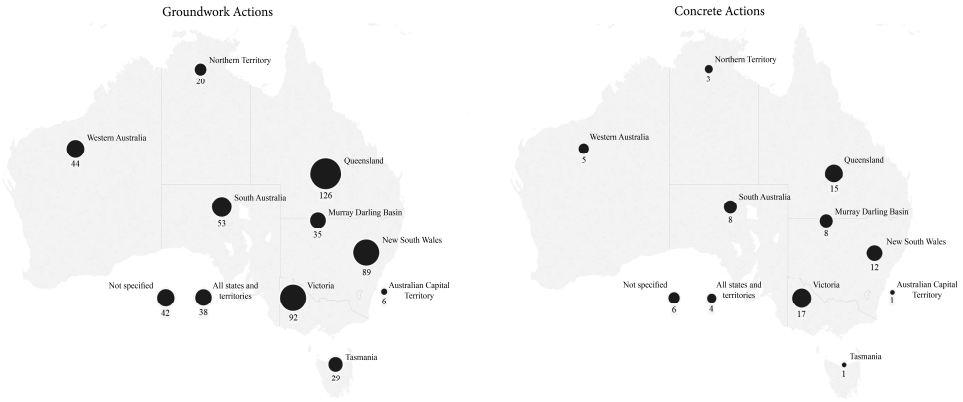

Fig. 4 Geographic distribution of groundwork and concrete adaptation actions across Australia

One explanation for this trend is that the majority of the Australian population (~77%) lives in these states (NSW: 7,480,228; VIC: 5,926,624; QLD: 4,703,193 habitants) (Australian Bureau of Statistics 2016). The country's three largest cities,

Sydney (NSW), Melbourne (VIC), and Brisbane (QLD), are also the capital cities of the three states, each located on the coast, and make up 20.1% (4,485,211), 19.7% (4,823,991), and 9.7% (2,270,800), or 49% in total, of Australia's national population. Another explanation that together with population concentration might account for the quantity of climate change adaptation research in these states is the location of the Great Barrier Reef, Gold Coast and Sunshine Coast in Queensland (important tourist destinations), and a primary agricultural industry in the Murray Darling Basin, most of which is located in these three states (see section 4.4)

Of these three states, Queensland has the highest number of peer-reviewed articles reporting adaptation actions (32%, n=126), and the highest number of articles reporting adaptation actions among Indigenous populations and in coastal and low-lying areas. All of the articles that focus on Indigenous populations report on research conducted with groups in geographically remote locations such as Torres Strait and Arnhem Land (e.g. McNamara et al. 2017).

4.4 Adaptation actions heavily focus on agriculture

Agriculture is the primary focus of 30% (n=117) of all included articles. 12% (n=45) of reviewed articles model the impacts of climate change on water availability for irrigation, yields under different climate and resource availability scenarios, the impacts of pests, and the potential of specific adaptation options in agriculture (e.g. Bennett et al. 2011). Another 9% (n=37) document stakeholder perspectives on climate change and adaptation in the agricultural industry, including the perspectives of primary producers (e.g. Kuehne 2014), and agricultural industry representatives (e.g. Fleming et al. 2015). Consistent with the geographic focus of all reviewed articles, most articles that focus on agriculture are concentrated in eastern Australia. Within the literature

focusing on agriculture, 20% (n=23) of included articles report on adaptation and agriculture in New South Wales, 21% (n=25) in Victoria, and 30% (n=35) in Queensland. In addition to these three states, the primary geographic focus of 15% (n=17) of literature reporting on adaptation and agriculture is the Murray-Darling Basin (MDB), which covers an area that crosses between South Australia, New South Wales, Victoria, and Queensland. In total, 18.7% (n=73) or all included articles focus on adaptation and agriculture in one or multiple of these four states.

In the MDB specifically, climate change has already been documented and includes extreme weather events (i.e. droughts), changes in precipitation patterns, and warmer temperatures with adverse effects on agricultural quality and production (Loch and Adamson 2015). Both groundwork and concrete adaptations have been reported, with most articles addressing adaptation to changing availability of fresh water (63%, n=22) (e.g. Lukasiewicz et al. 2016). Groundwork adaptation actions include understanding farmers' perspectives and attitudes on climate change adaptation, modelling yield production for different farm management and climate scenarios, and evaluating costs and benefits of various irrigation practices (e.g. Alston et al. 2018). Concrete adaptation actions mostly focus on freshwater management, irrigation efficiency and crop diversification, as well as earlier planting and sowing (e.g. Klocker et al. 2018). There is a sense of agreement in the literature that infrastructural measures for freshwater management are affecting environmental flows, ultimately reducing the future resilience of the wetland ecosystems in the MDB (Pittock 2013; Pittock and Finlayson 2013).

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4.5 Coastal adaptation is prominent and predominantly addressed in groundwork adaptation actions

Approximately 85% of the Australian population lives within the coastal region, with more than $226 billion in coastal infrastructure at risk of inundation or erosion based on projected sea-level rise by 2100 (Australia Government 2009). 21% (n=83) of reviewed articles focus on adaptation in the coastal zone, of which 96% (n=80) describe groundwork adaptation actions. These actions mostly seek to protect infrastructure and reduce vulnerability to extreme weather events (43%, n=36), sea-level rise (52%, n=43), and climate change in general (50%, n=42) by assessing the adaptation potential of concrete actions. Most concrete actions can be described as "hard engineering" responses such as building sea walls and groins to cope with rising sea level and extreme storm events, with only a few articles describing soft engineering responses such as increasing wind classifications for new housing to adapt to increasing cyclone and severe storm intensity (e.g. Stewart et al. 2014).

Of the 83 articles focusing on adaptation in the coastal zone, most are from eastern Australia: 27% (n=22) report on coastal adaptation in New South Wales, 25% (n=21) in Victoria, and 55% (n=46) in Queensland. Most adaptation actions in these three states respond to temperature increases, climate change in general, sea-level rise and increased frequency and intensity of severe weather events like cyclones. Sea-level rise is of particular interest to this region, due to the exposure of capital infrastructure to the sea and the risk of inundation, damage, and loss of habitable land (Lin et al. 2014). The high volume of groundwork actions reported in this region is consistent with the findings of Bradley et al. (2015), in which the majority of coastal local governments are either beginning to understand the implications of climate change or planning to adapt

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to its effects. A few articles analyse stakeholder perceptions of risk and their response potential to climate change (e.g. Elrick-Barr et al. 2015).

4.6 Health adaptations focus on extreme weather events

The implications of and adaptation to the health impacts of climate change is prominent in the literature. Of the included articles, 14% (n=55) focus on the health implications of climate change, with a specific focus on the impacts of drought (n=8) and heat stress (n=14). Within these 55 articles, some focus on climate change and mental health, either within specific groups or in response to specific climate-related stressors. For example, several articles explore the relation between climate change, mental health, and adaptation options in the context of food insecurity, socio-economically stressed populations, or rural populations (e.g. Bowles 2015). Some of these articles seek to understand how farmer's mental health is affected by drought and two articles, the only articles reviewed that address gender, examine the effect of drought for men and women (e.g. Alston 2011; Hart et al. 2011). Reported concrete actions include the development of a rural mental health support telephone line (Hart et al. 2011), and capacity building in rural areas including training mental health and social workers (Anderson 2009). Beyond mental health, there is also a focus on a variety of other health-related issues including: increased risk of vector-borne diseases such as dengue fever and Ross River virus (e.g. Beebe et al. 2009); and opportunities to improve infrastructure and city planning in light of climate change, such as green spaces and health service infrastructure (e.g. Bambrick et al. 2011).

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4.7 Concrete adaptation actions are sometimes followed by a second generation of groundwork adaptation actions

Some articles report on groundwork adaptation actions that occur after concrete adaptation actions have been taken. This second generation of groundwork adaptation actions analyses the efficiency, effectiveness, success and/or profitability of concrete adaptation actions, as well as the potential for maladaptation. Examples include analyses of the feasibility and profitability of snowmaking in the Australian ski industry (e.g. Hennessy et al. 2008;), studies on the potential of water tanks, provided to households to deal with changing water availability, to become mosquito larval sites (e.g. Beebe et al. 2009), and research on the use of levees as adaptation measures in the development of flood prone areas (e.g. Wenger 2015).

5.0 Discussion

The findings of this review provide compelling evidence against the hypothesis that Australia is a laggard in climate change adaptation. It is notable that most of the reported climate change adaptation initiatives in Australia can be grouped as groundwork actions, with a focus on documenting stakeholder perspectives on climate change and their attitudes towards adaptation, and scenario planning and/or modelling. These actions are precursors to the more tangible, concrete actions, which have been the focus of previous reviews. This finding tells us that the Australian government and research community are indeed advanced in adaptation planning for climate change, having generated a substantive body of useable science related to climate change and adaptation issues, and are well positioned to advance the research agenda from adaptation preparation to implementation.

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The finding that government funding for adaptation research influences adaptation reporting is significant. Many people, communities, industries and governments deal with changing climatic conditions on a daily basis, without labelling or reporting their actions as adaptation *per se.* To track adaptation, actions need to be recorded, which is often done through research. This reinforces the importance of funding for climate change adaptation research that results in measureable outputs like peer-reviewed publications. Furthermore, reviews of climate change adaptation should be performed periodically and capture the longest time-scale possible since adaptation is an on-going and iterative process.

The review shows that Australia shares most of the characteristics for climate change adaptation identified in developed nations outlined by Ford et al. (2011). Nonetheless, adaptation in Australia has its singularities: while in other developed nations climate change adaptation is dominated by actions in the infrastructure, transportation and utilities sectors, Australia has a stronger focus on agriculture and freshwater management. This is likely a reflection of the pre-adaptation state of the nation's climate, being the driest inhabited continent globally and exposed to long periods of drought.

A limitation of this review is the exclusive focus on peer-reviewed literature. It is acknowledged that not all adaptation efforts are captured in the peer-reviewed literature and thus some were surely missed in this study. The findings are thus best characterized as providing a proxy of the state of adaptation in Australia from the perspective of the peer-reviewed literature.

The findings of this review are significant as they help us to better understand how climate change adaptation is happening in Australia at a time when tracking adaptation is critical in national and international climate change financing and decision-making. A

misrepresentation of the state of adaptation in a particular place, in this case Australia, risks negating important steps needed to formulate sustainable adaptation actions from policy-making processes and could lead to maladaptation (Magnan et al. 2016). This review not only provides a proxy of the state of adaptation in Australia from the perspective of the peer-reviewed literature, but it also shows publishing gaps that need to be filled to provide a more complete characterisation of how Australia is adapting to climate change.

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Author contributions:

T.D.P. conceived the project, designed the methodology, collected and analyzed the data, and led writing the paper; E.R. collected and analyzed the data and helped write the paper; D.F. and J.D.F. analyzed the data and helped write the paper.

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The authors declare no conflicts of interest.

Appendix A. Supplementary Materials

6.0 References

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