Household adaptation to climate change and the resilience of Australian urban areas

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Abstract:
Urban areas are important sites for climate change adaptation. Consequently, integrating climate change into urban policy and planning has received recent academic attention; less attention however has been placed on the interface between urban governance and local scale adaptive action. This is despite consensus that local-level capacities are critical for successful adaptation. In Australia, building community capacity to adapt is mandated in adaptation and hazard management policy, yet there is limited understanding of current household response and influencing factors; hindering the development of evidence-based policy seeking to develop capacity for action. To address this gap in understanding, a systematic literature review of household adaptation in Australian urban areas was conducted, combined with case study research examining household adaptation in two Australian coastal communities. The assessment indicates pro-environmental actions are more frequent than actions to reduce vulnerability to environmental hazards; and adaptation is limited. Further, despite the importance of household adaptation in contributing to urban resilience, action is unlikely to be autonomous. Therefore the concept of shared responsibility advocated by government agencies, which places onus for adaptation on households, may require refinement to accommodate constraints and limits to household action.

1. Introduction

Urban areas are increasingly seen as important sites for climate change adaptation (Hughes and Sarzynski, 2015). From capital cities to suburban regions, vulnerability to the impact of climate change is a function of the built, social, natural, political and cultural conditions unique to urban spaces. Urban governance underpins the ability to prepare and respond to climate impact (Fatti and Patel, 2013) and consequently integrating climate change into urban policy and planning has received recent academic attention (Bahadur and Tanner, 2014, Glaas *et al.*, 2015). Less attention however has been placed on the interface between urban governance and local scale adaptive action, despite consensus that local-level capacities are critical for successful adaptation (Wamsler and Brink, 2014, Moser and Pike, 2015). By 2050, approximately 80 per cent of the infrastructure of Australian cities will have been built prior to 2010 (City of Melbourne, 2010). Consequently, property owners and those residing within urban spaces will play an important role in retrofitting existing built form and adapting behaviours and routines to accommodate the physical and environmental conditions within climate vulnerable urban regions.

With a focus on the local scale of response, the role of the household in contributing to urban resilience is acknowledged in national adaptation plans that advocate a shared approach to climate adaptation (DCCEE, 2010a, Council of Australian Governments, 2011). However, whilst the importance of households' adapting to climate change is recognised, the promotion of action and capacity to act is currently mandated in the absence of information on action at this scale. To date, the focus on adaptation in Australia, as in other developed nations, has been on actions implemented by government authorities and private organisations (Berrang-Ford *et al.*, 2011, Ford *et al.*, 2011). In particular, a focus on asset loss and disruptions to business continuity, particularly in the coastal zone, has been the base of adaptation planning and policy in Australia (Smith *et al.*, 2011, Nalau *et al.*, 2015). In the absence of information on actions currently implemented by households and influencing factors, the existing contribution to urban resilience, as well as gaps in action that could be targeted via initiatives seeking to promote action, remain unclear – hampering efforts to increase resilience.

To address gaps in understanding, this paper provides an account of household adaptive action within Australian urban areas, based on systematic literature review and case study research. There is a lack of empirical research on adaptation at the household scale. Nonetheless, the results highlight three key issues regarding household adaptive action and the resilience of urban areas: first, adaptive action is currently limited; second, issues of equity will be more pressing as the requirement for more costly adaptive actions increases; and third, a challenge exists in reconciling the external support needed to promote household action and a policy position that advocates household self-reliance.

3. Methods

3.1 Systematic Literature Review

The systematic review followed the method of Porter *et al.* (2014), who conducted a systematic review of household adaptation in the United Kingdom. Using Web of Science, a topic search of papers on household adaptation in Australian cities was undertaken. Different combinations of keywords were used to capture climate change and its manifestations (e.g. change, variability, extremes) (Table 1). Five hundred and twenty-nine documents were returned, imported into endnote and inclusion and exclusion criteria were applied (Table 1) (Supplementary Figure 1).

Table 1: Key word searches and inclusion/exclusion criteria

Key word searches	Climat*, chang*, Variab*, extreme*, Resilien*, Vulnerab*, Risk*, Adapt*, prepare*, disaster*, recovery*, capacity*, behav*, Australia*, Individual*, Household*, Communit*, Group*, Famil* Home*
Inclusion Criteria (Phase 1 Key word search)	Exclusion Criteria (Phase 1 Key word search)
• English Language • 1st January 2010 and 7th May 2015 • Indexed in Web of Science • Peer-reviewed publications (full text available)	• Non-English Language • Pre-2010 and after 8th May 2015 • Neither indexed nor available from Web of Science • Others (editorials, reviews, book chapters, meetings etc) (full text un-available)
Inclusion Criteria (Phase 2: Title and Abstract Review)	Exclusion Criteria (Phase 2: Title and Abstract Review)
• Adaptation in human systems • Adaptive response(s) at household scale (including sustainability responses) • Practical/empirical focus • Australian urban regions	• Adaptation in natural systems (e.g. plants, animals, microbes) • Not household/individual scale of response, or perceptions of risk and policy options implemented at other scales (e.g. government) • Carbon reduction only • Conceptual focus only • Non-Australian non-urban regions (e.g. farming, remote indigenous community)

As detailed in Table 1, only empirical, peer-reviewed publications, written in English and focusing on present-day adaptive responses in Australian cities were included. Exclusions included adaptation in non-urban areas (e.g. farming) or natural systems (e.g. biological responses), conceptual articles, articles that only considered carbon reduction, or focused solely on impact. As sustainability actions within the home are often framed as climate adaptation (e.g. energy consumption) such papers were also included in the review – thus incorporating actions that deliver mitigation outcomes. Papers published prior to 2010 were excluded as they were captured in the review process for the IPCC's 2011 assessment report, where there was relatively little research on household adaptation (Mimura *et al.*, 2014). Twenty-five papers met the review criteria and were subject to full review. Of those reviewed, only 11 (2% of the initial search) addressed the review questions and/or criteria. An identifier was assigned to each publication and is used to refer to each individually (Table 2). The reviewed papers covered household action for different hazards including heatwaves (4), flood (1), wildfire (1) and drought and sea-level rise (1). The remaining papers (5) addressed sustainability dimensions of climate change. Quantitative (7), qualitative (2) and mixed-methods (3) approaches were adopted.

The Australian National Climate Change Adaptation Research Facility (NCCARF) funds adaptation research that may not be published in peer-reviewed journals. To incorporate the findings of this nationally significant research program completed project reports were reviewed by title and summary for reference to household/ individual/ community adaptation in Australian urban areas (e.g. NCCARF, 2012b, NCCARF, 2012a). Eighteen reports were identified. Each was reviewed applying the same inclusion/exclusion criteria, leaving eight for full review. The reviewed reports addressed heatwave (2), flood (1), cyclone (1) and climate change sustainability/mitigation (4). The reports are referred to as 'grey' literature (Table 2).

A qualitative scorecard was used to record the characteristics of each article, including authorship, research focus, and methods. Following Porter *et al.* (2014), three questions were asked: (1) what actions are households taking to adapt to climate change? (2) what are the drivers and barriers to action? and (3) will these actions happen autonomously?

Table 2: Reviewed literature

ID	Type	Hazard	Reference
1	PR	Drought and Sea-level rise	Higginbotham N, Connor LH, Baker F (2014) Subregional differences in Australian climate risk perceptions: coastal versus agricultural areas of the Hunter Valley, NSW. Regional Environmental Change 14 (2):699-712.
2	Grey	Flood	Bird D, King D, Haynes K, Box P, Okada T, Nairn K (2013) Impact of the 2010-11 floods and the factors that inhibit and enable household adaptation strategies. National Climate Change Adaptation Research Facility (NCCARF), Gold Coast
3	PR	Climate change sustainability: GBR impact	van Riper CJ, Kyle GT, Sutton SG, Yoon JI, Tobin RC (2013) Australian residents' attitudes toward pro-environmental behaviour and climate change impact on the Great Barrier Reef. Journal of Environmental Planning and Management 56 (4):494-511.
4	PR	Climate change sustainability: GBR impact	Yoon JI, Kyle GT, Van Riper CJ, Sutton SG (2013) Testing the Effects of Constraints on Climate Change-Friendly Behavior among Groups of Australian Residents. Coastal Management 41 (6):457-469.
5	PR	Heatwave	Akompab DA, Bi P, Williams S, Grant J, Walker IA, Augoustinos M (2013) Heat Waves and Climate Change: Applying the Health Belief Model to Identify Predictors of Risk Perception and Adaptive Behaviours in Adelaide, Australia. International Journal of Environmental Research and Public Health 10 (6):2164-2184.
6	PR	Heatwave	Banwell C, Dixon J, Bambrick H, Edwards F, Kjellstrom T (2012) Socio-cultural reflections on heat in Australia with implications for health and climate change adaptation. Global Health Action 5:1-9.
7	PR	Heatwave	Loughnan ME, Carroll M, Tapper N (2014) Learning from our older people: Pilot study findings on responding to heat. Australasian Journal on Ageing 33 (4):271-277.
8	PR	Heatwave	Mee KJ, Instone L, Williams M, Palmer J, Vaughan N (2014) Renting Over Troubled Waters: An Urban Political Ecology of Rental Housing. Geographical Research 52 (4):365-376.
9	Grey	Heatwave	Saman W, Boland J, Pullen S, de Dear R, Soebarto V, Miller W, Pocock B, Belusko M, Bruno F, Whaley D, Pcokett J, Bennetts H, Ridley B, Palmer J, Zuo J, Ma T, Chileshe N, Skinner N, Chapman J, Vujinovic N, Walsh M, Candido C, Deuble M (2013) A framework for adaptation of Australian households to heat waves. University of South Australia, National Climate Change Adaptation Research Facility (NCCARF)
10	PR	Climate change sustainability	Dowd A, Ashworth P, Carr-Cornish S, Stenner K (2012) Energymark: Empowering individual Australians to reduce their energy consumption. Energy Policy 51:264-276. doi:10.1016/j.enpol.2012.07.054
11	PR	Climate change sustainability	Hall N, Romanach L, Cook S, Meikle S (2013) Increasing Energy-Saving Actions in Low Income Households to Achieve Sustainability. Sustainability 5 (11):4561-4577. doi:10.3390/su5114561
12	PR	Climate change sustainability	Waitt G, Caputi P, Gibson C, Farbotko C, Head L, Gill N, Stanes E (2012) Sustainable Household Capability: which households are doing the work of environmental sustainability? Australian Geographer 43 (1):51-74. doi:10.1080/00049182.2012.649519
13	Grey	Climate change sustainability	Unsworth K, Russle S, Lewandowsky S, Lawrence C, Fielding K, Heath J, Evans A, Hurlstone MJ, McNeill I (2013) What about me? Factors affecting individual adaptive coping capacity across different populations. The University of Western Australia, National Climate Change Adaptation Research Facility (NCCARF).
14	Grey	Climate change sustainability	Instone L, Mee KJ, Palmer J, Williams M, Vaughan N (2013) Climate change adaptation and the rental sector. University of Newcastle, National Climate Change Adaptation Research Facility (NCCARF).
15	PR	Wildfire	Prior T, Eriksen C (2013) Wildfire preparedness, community cohesion and social-ecological systems. Global Environmental Change-Human and Policy Dimensions 23 (6):1575-1586. doi:10.1016/j.gloenvcha.2013.09.016
16	Grey	Climate change sustainability	Reser, J.E.A., 2012. Public risk perceptions, understandings and responses to climate change and natural disasters in Australia, 2010 and 2011. Gold Coast.
17	Grey	Heatwave Flooding	Hanson-Easey, S., Bi, P., Hansen, A., Williams, S., Nitschke, M., Saniotis, A., Zhang, Y. & Hodgetts, K., 2013. *Public understanding of climate change and adaptation in South Australia.* Gold Coast.
18	Grey	Heatwave	Hansen A, Bi P, Saniotis A, Nitschke M, Benson J, Tan Y, Smyth V, Wilson L, Han GS (2013) Extreme heat and climate change: Adaptation in culturally and linguistically diverse (CALD) communities. National Climate Change Adaptation Research Facility (NCCARF), Gold Coast
19	Grey	Cyclone	Boon HJ, Millar J, Lake D, Cottrell A, King D (2012) Recovery from disaster: Resilience, adaptability and perceptions of climate change. National Climate Change Adaptation Research Facility (NCCARF), Gold Coast

3.2 Case Study Research

To verify and supplement the findings of the systematic literature review, comparative case-study research was conducted in two Australian coastal communities: the City of Mandurah, Western Australia, and Moreton Bay coastal region, Queensland (Figure 1). The case sites were selected to explore hazard vulnerability and adaptive capacity in Australian coastal communities[1]. These urban communities contain features representative of coastal cities throughout Australia, such as rapidly growing population, households with diverse socio-demographic characteristics (from young families to elderly residents, low income to high income households) (Table 3) and vulnerability to climate hazards, including sea-level rise, extreme heat and severe storms. Development in the coastal margins, including marina developments, has exacerbated the physical vulnerability of these sites. As such, each is vulnerable to sea-level rise and associated coastal erosion and flooding (DCCEE, 2009); and adaptation is considered paramount to maintain social and environmental values (DCCEE, 2010b). Household perception of vulnerability to environmental hazards is, however, low (Elrick-Barr *et al.*, 2015). As in other locations (Hendrickx and Nicolaij, 2004, Gattig and Hendrickx, 2007), personal risks (e.g. economic risk) rather than environmental risks are a more pressing concern for local residents (Elrick-Barr *et al.*, 2015).

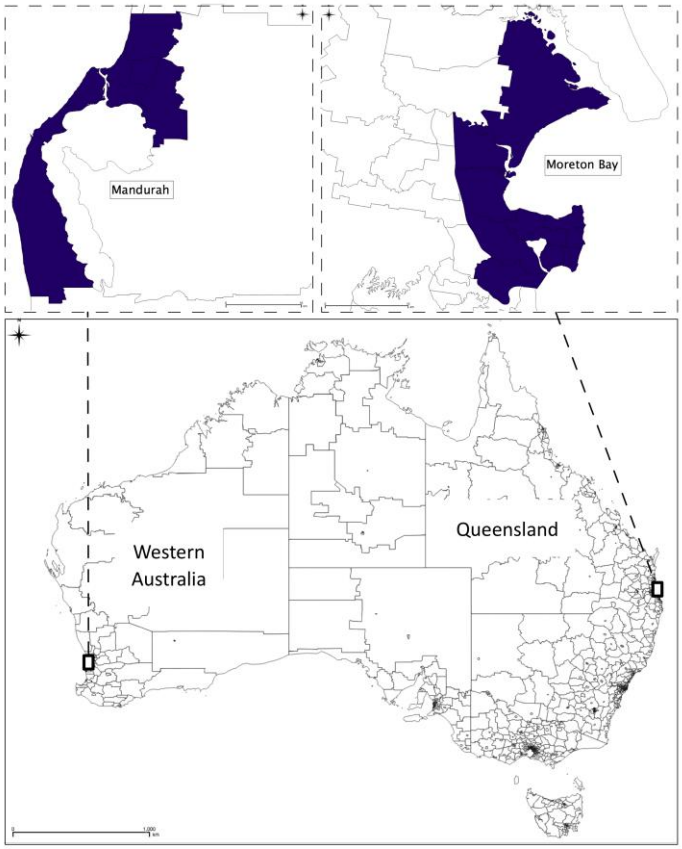

Figure 1: Case-study locations

The local government authorities in each area have conducted climate change risk assessments (e.g. Burton *et al.*, 2009, Elrick *et al.*, 2009). In Mandurah, the results of climate change impact studies and associated responses by the local authority are communicated to residents through public information sessions; online reports; and State government impact assessments (City of Mandurah, 2014). In Moreton Bay, hazard preparation advice is disseminated to the community through hazard management campaigns (e.g. Get Ready Queensland and Harden Up)[2]. The communities provide an opportunity to explore the influence of household characteristics (i.e. varying social advantage/disadvantage), exposure to climate hazards, levels of trust, perceptions of climate change, and State and local management policy on household action.

[1] As part of a larger ARC funded project entitled: Community Vulnerability and Extreme Events: Development of a Typology of Coastal Settlement Vulnerability to Aid Adaptation Strategies (DP1093583).
[2] https://getready.qld.gov.au/; http://hardenup.org/about-harden-up.aspx

Table 3: Case-study community characteristics

	City of Mandurah	Western Australia	Moreton Bay Coastal Area	Queensland
Land area	174 sq. km.		252 sq. km.	
Population (2011)	67,227		129,886	
Population growth	5% per annum (2006 – 2011)		4% per annum (2006 – 2011)	
Age dependency ratio[3] (2011)	64.5	47	57.5	50.2
Old age dependency ratio[4] (2011)	33.5	28.9	24.7	20.4
Renting (2011)%	31.3	29.2	37.1	33.2
Single person households (2011)%	24.9	23.8	24.7	22.8
Household income less than $600/wk (2011)%	30.3	21.1	15.7	13
Household income more than $3,000/wk (2011)%	8.7	14	6.7	10.9
Unemployed (2011)%	7.1	4.7	9.8	6.2

Source: (Modified from Elrick-Barr *et al.*, 2015)

3.2.1 Data collection

A mixed-method approach was adopted to obtain information on household adaptive action, from mitigation actions that address the threat of climate change to hazard specific measures (for example, for severe storms or heatwaves). A postal-questionnaire was delivered to households randomly selected from residential databases provided by each local government authority. In total, 1797 postal surveys were distributed, followed by 493 hand-delivered surveys. A total of 400 completed surveys were returned representing a response rate of approximately 20%. The survey contained pre-defined household actions for climate change (termed pro-environmental action) and environmental hazards, and pre-defined barriers to action (e.g. income, access to information, previous experience, government action). The respondents identified actions previously taken and the most significant barrier to action. A majority of adaptation research examines a select hazard and responses in isolation. The case study enabled exploration of pro-environmental actions and environmental hazard response in unison, allowing comparison in the level of action and influencing factors.

Survey respondents had the opportunity to self-nominate to participate in a follow-up interview. Forty-six respondents identified their willingness to participate. The demographic characteristics of each household, as provided in their survey responses, were profiled to select those representing the diversity in the communities. A total of 17 telephone interviews were conducted with household representatives, eight in Mandurah and nine in Moreton Bay. During the interview, the household respondent discussed the impact and their anticipated responses to three hazard scenarios, including two hazards the households are familiar with (i.e. severe storm, heatwave) and one hazard the households are vulnerable to, but have less direct experience of (i.e. sea-level rise) (Table 4). Interviews lasted between 15 and 40 minutes and were transcribed verbatim.

Table 4: Scenario hazards

Hazard	Description
Severe storm	A severe summer storm hits [Moreton Bay/Mandurah]. Storm impact includes high winds, loss of power, localised flooding, fallen trees and damaged power lines. Your household loses power until midday the following day and you experience minor roof damage, which results in limited water damage in the living room of your home.
Heatwave	There is a heat wave in [Mandurah/Moreton Bay]. The impact includes health issues such as heat stress, water restrictions, trouble sleeping at night, and limited opportunities for outdoor recreation. During the heat wave, your household has a power blackout that lasts for several hours

[3] Age dependency ratio (% of working-age population) is the ratio of dependents (i.e. people younger than 15 or older than 64), to the working-age population (i.e. those aged 15-64)
[4] The old age dependency ratio is the ratio of people aged 65 years and over to the working age population (i.e. those aged 15-64).

Hazard	Description
Sea-level rise	SLR in [Mandurah/Moreton Bay] creates gradual inundation in low-lying areas and will occur incrementally over time. SLR can also exacerbate coastal erosion through raised water levels that affect higher areas of the coastal dune. SLR may result in some areas of the region being 'cut-off' from others where roads and services are located in low-lying areas. In addition, there may be instances of damage to infrastructure located in low-lying areas or on the coastal fringe.

3.2.2 Data analysis

Factors influencing the implementation of action, as identified in the systematic literature review, were assessed applying cross-tabulation, chi-square analysis and binary logistic regression. For example, household characteristics (income, family type, homeownership) and normative factors such as climate change belief and trust in others, were analysed against the implementation of pro-environmental and environmental hazard action. The pre-defined actions for each category of action were grouped into meaningful categories based on action type (Table 5) and independent variables were analysed against categories of action.

Table 5: Adaptation action types

Category	Actions
Pro-environmental action	
Resource	Reduced motor vehicle use, installed energy efficient light bulbs, reduced the amount of water around the house and garden, use energy efficient appliances and reduced gas or electricity used around the home
Infrastructure	Installed rainwater tanks, installed solar power systems, increased home insulation
Governance	Signed a petition or voted for a particular political party
Environmental hazard action	
Preparation	Developed a household evacuation plan, prepared a household emergency kit
Private action	Made building or property adjustments, moved house
Collective action	Joined recovery effort, joined political action group, joined local conservation efforts, donated money to a group working to prevent related problems
Governance	Given testimony, voted for a particular political party, contacted elected officials or government agencies, signed a petition about an issue, attended a government meeting

Transcribed interviews were imported into NVIVO, a qualitative data analysis program, and interpretively analysed (Yanow and Schwartz-Shea, 2006). Key themes arising from responses on household actions and barriers to action were identified.

4. Results

4.1 What actions are being taken?

Literature review

Following Porter *et al.* (2014) and Kent *et al.* (2013), actions can be categorised as adaptations or coping responses. Coping responses are intuitive, inexpensive, and accessible responses taken at the outset of, and/or during, an extreme weather event, or in its immediate aftermath. Adaptations are more complex, costly and challenging anticipatory actions, taken in the absence of an imminent threat to protect the household or area from current or future risks. To respond to the impact of heatwaves, coping responses were adopted, including drinking water, seeking protection from shade, using air-conditioning and fans, cross-ventilation and changing timing of behaviours to avoid peak heat periods (#5,6,7,9,17, 18). Adaptation actions, such as home insulation and increased shading to offset air-conditioning use, were rarely reported (#9,17). In culturally and linguistically diverse communities family networks were drawn on to look after aged relatives at home and to check on other community members during extreme heat events (#18).

Two of the reviewed papers addressed household response to flood risk, one in a flood prone community (#2) and one in a non-flood prone region (#17); while cyclone preparation was examined in a community post-impact (#19). In the flood prone region, adaptation actions were cited, including

anchoring water tanks or improving drainage around the home, but were adopted by less than half of those surveyed/interviewed (#2). Other coping responses such as regularly clearing ditches and drains were more widely practiced. Similarly, adaptive action in the community exposed to cyclone risk was minimal, with only 4% of surveyed households having an emergency response kit, while 36% claimed they undertook no preparations (#19). In the non-flood prone region, very few pragmatic strategies, such as 'using sandbags around the house' (3%) were cited, leading the authors to suggest that perceived risk from flooding engenders few pragmatic adaptation strategies (#17) (Hanson-Easey *et al.*, 2013). For drought and sea-level rise (#1), sustainability actions (e.g. conservation of water and electricity) were cited to address impact, while adaptation actions such as private property adjustments, or moving were unpopular and rarely taken (#1).

Pro-environmental actions include resource conservation (water and energy), recycling, food choice and vehicle use. While these actions predominantly mitigate rather than adapt to the impact of climate change, they are actions households often cite as part of their strategy to respond to climate change impact (Ipsos MORI Research Institute, 2013). Resource related mitigation actions dominated, with recycling and resource conservation (e.g. using less electricity) the most widely adopted actions (#3,10,12,14, 16). Limited action was associated with other mitigation strategies such as reducing air travel, carpooling, using public transport, and buying carbon offsets (#16).

Case-study communities

In the case-study communities, pro-environmental action was more frequent than action to prepare for environmental hazards (Figure 2). Similar to the findings of the literature review, a majority of the surveyed households (over 60%) had taken resource related mitigation action (e.g. using energy efficient light bulbs, saving water and reducing power use) (Figure 2). Reducing vehicle use was often considered but less often taken (following Reser *et al.*, 2012), perhaps due to the spread out nature of Australian cities and generally poor public transport links (Baum *et al.*, 2013).

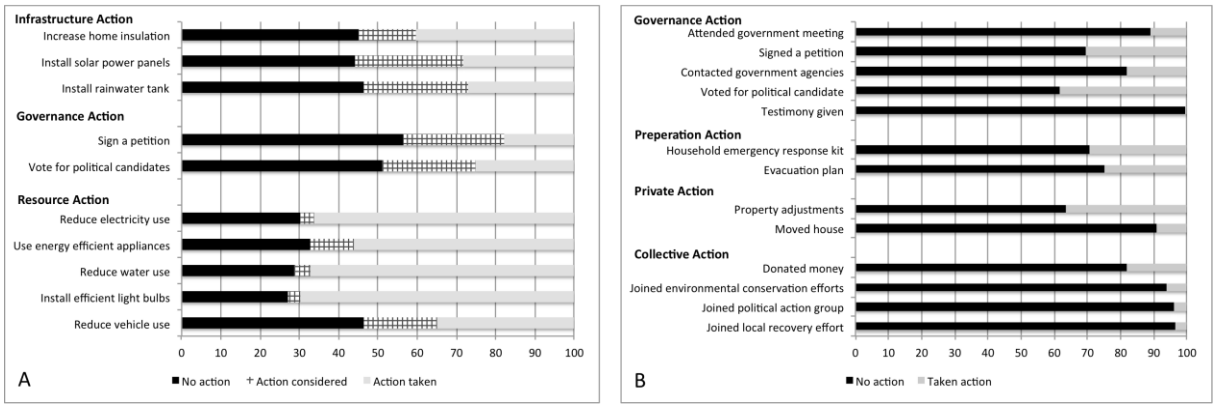

Figure 2 Implementation of pro-environmental actions (A) and environmental hazard actions (B), by action type

Collective action (e.g. joining local conservation efforts, political action groups or recovery efforts) was the least frequently adopted action; while preparatory and private action, such as making property adjustments and having an evacuation plan, were reported by approximately 30% of surveyed households (Figure 2). In the absence of additional information on the types of property adjustments made it is, however, difficult to verify if they were 'adaptive' following the definition of Porter et al. (2014). Therefore, interviews provided further detail on the type of actions household would adopt to respond to environmental hazards . To respond to heatwaves, respondents cited behaviour modification strategies or using external services for relief during the event: "… all you can really do … is find a cool spot and drink lots of water... If it were that overpowering you would be best to head down to a supermarket to try and find some relief" [ID 264]. To respond to severe storms, households took preparatory action upon receipt of warnings (i.e. coping responses). In addition, home insurance and external support services (i.e. emergency response services), were part of the response strategy: "I would just speak to the insurance first and then try and get it sorted out" [ID 292]; "I suppose that natural thing would be to ring the SES and say I have a problem with the roof would you be able to secure it" [ID 264].

For sea-level rise, respondents were uncertain regarding the responses they would take and frequently referenced other hazards (e.g. tsunami or severe flood) to visualise impact and associated actions. Only one household cited lobbying council as a strategy to address sea-level rise: "All I can

do is write letters to local government and ask what they are going to do about it. They need engineers to do something" [ID 344]. Further, when asked what decisions influence their household's vulnerability to sea-level rise, 25% of respondents referenced pro-environmental behaviours as actions to mitigate the impact of sea-level rise.

The results support the findings of the systematic literature review, where a dominance of coping strategies to respond to environmental hazards was identified. With the inclusion of an uncertain/novel hazard (sea-level rise), a tendency to reference coping strategies (e.g. sand bags) remained, in combination with a perception that exposure of the household to such hazards was limited: "There is not a lot of vulnerability here for us personally. We are on a high dry block" [ID344]. Even in cases where respondents assigned high-risk perception to sea level rise, they remained uncertain regarding the actions their household could take. Overall, there was limited reference to adaptive approaches to manage both familiar and novel climate hazards.

4.1 What are the drivers and barriers to action?

Literature Review
Past experience was associated with the implementation of action for all reported hazards, including drought, flood and heatwaves, while perception of risk was an important driver for action for hazards such as wildfire and flood. Social conditions including perceived social norms, opportunities for social participation, community cohesiveness and collaborative goal setting, were associated with hazard specific (e.g. wildfire) (#15) and pro-environmental action (#10,11). For example, low perceptions of household capability to implement action, low perceived effectiveness of actions in achieving positive outcomes, and perceived conflicts with social norms were reported barriers to pro-environmental behaviours (Supplementary Table 1). Financial resources impacted household access to air-conditioning (Banwell *et al.*, 2012, Saman *et al.*, 2013), while the permanent and inflexible nature of housing design reportedly inhibited action to address risks posed by flood (Bird *et al.*, 2013) and extreme heat (Mee *et al.*, 2014).

The limited sample of literature exploring household adaptation in Australian urban areas constrains the ability identify key trends. For example, from the nineteen reviewed documents reporting on household action, different hazard types and influencing factors were examined. Even for studies exploring the same action type (i.e. pro-environmental action), there were alternate perspectives on the influence of independent variables (Supplementary Table 1). For example, Waitt *et al.* (2012) argue awareness of climate change does not influence the implementation of pro-environmental action, while Dowd *et al.* (2012) found a positive relationship between the two. Despite this, social processes (such as risk perceptions, perceived action efficacy, responsibility and self-efficacy) emerged as important in influencing mitigation and adaptation action.

Case-study communities
In the case-study communities, past experience, perception of local area vulnerability and a belief that climate change influences local area hazards were associated with the implementation of preparatory and private action (Table 6); reinforcing the findings of the reviewed literature (namely, Keogh *et al.*, 2011, Akompab *et al.*, 2013, Bird *et al.*, 2013, Prior and Eriksen, 2013, Higginbotham *et al.*, 2014). While household income was uncovered as a barrier to action in the reviewed literature, there was no association between income level and the implementation of action in the case-study communities (Table 6). Furthermore, household income was not significantly associated with perceptions of finance as a barrier to action, suggesting some households may view spending financial resources on preparatory action a luxury despite income level. Households citing access to financial resources as a barrier to action were also just as likely to have taken action to prepare for environmental hazards as those households that did not consider it a barrier. Finally, in accordance with the findings of the literature review, perceptions of trust, self-efficacy, awareness, experience and household characteristics (e.g. homeownership) were associated with the implementation of pro-environmental action (Table 6).

Despite the strong association between risk perceptions and the categories of pro-environmental and environmental hazard action, perceptions of local vulnerability only increased the likelihood of infrastructure or preparatory action. Private action was more likely when a respondent was not in rental accommodation, as too was infrastructure and resource related action. When the household reported a tendency to plan ahead, they were twice as likely to have taken governance or infrastructure action. The independent variables, however, only explained a small proportion of the variance in each category of action (from 12% to 20%) (Table 6) suggesting other factors influence whether a household chooses to act. Perceived self-efficacy and responsibility for action were not

reported in the survey; however, interview results indicate strong perceived capability to implement coping strategies and a responsibility to take actions within the coping capacity of the household. Overall, the comparative examination of influencing factors by action type indicates variation in influencing factors depending on the category of action, with implications for targeting adaptive behaviours.

Table 6: Factors associated with the implementation of action, by action type

	Pro-environmental action			Environmental hazard action			
	Resource	Governance	Infrastructure	Collective	Preparatory	Private	Governance
Chi Square							
Trust							
Political leaders to act in interest of my household	N..						
Government will take action on climate change	N.		N.				
Governments will effectively coordinate disaster response							
Social norms and perceived collective-efficacy							
Other residents will not cause my household harm						N.	
Individual households are capable of preventing harm	Y.		Y..				
Planning and decision-making							
A tendency to plan ahead		Y..	Y.				Y.
There are opportunities to influence decisions of importance							
Awareness, past experience and perceptions of risk							
Climate change influencing local environmental hazards	Y..	Y..	Y..	Y..		Y..	Y..
Affected by an environmental hazard in the past	Y..	Y..			Y..	Y..	Y..
Local area is vulnerable to environmental hazards	Y..		Y..		Y..	Y..	Y.
Household characteristics							
Homeownership (ref: renting)	N..		N..				
Income (ref: Low)							
Case study area (ref: Mandurah)			N..				
Logistic Regression							
Precent of variance in action explained by the model	*17*	*12*	*20*	*-*	*13*	*10*	*13*
Political leaders will act in interest of my household							
Individual households are capable of preventing harm			2				
Opportunity to influence decisions							
Climate change is influencing environmental hazards		2					
Affected by an environmental hazard in the past		2					2
Local area is vulnerable to environmental hazards			2		3		
A tendency to plan ahead		2	2				
Homeownership (ref: *do not* rent)	2.5		3.5			2	

[a] N indicates disagreement with the statement or reference value; Y indicates agreement with the statement or reference value; showing a significant proportional difference in the number of households that have taken the category of action (i.e. households that disagree (i.e. N) or agree (i.e. Y) with the statement are more likely to have taken the action).
[b]. Significant at α<0.05; .. Significant at α<0.01
[c] Values indicate the odds ratio derived from logistic regression analysis (B value). Odds ratios are shown for statistically significant predictor variables at α<0.05. For example, the likelihood a household had taken preparatory action increased 3 fold if they perceived their local area vulnerable to environmental hazards.
[d] Household income, case study area and trust in governments and other residents were not significant determinants in the regression models and were therefore removed from the table.
[e] Nagelkerke R Square values indicate the proportion of variance in action explained by the model.
[f] The sample reported to have taken collective action was too small for logistic regression analysis.

4.3 Will action be autonomous?

The reviewed literature suggests adaptation is unlikely to be autonomous. Adaptive action is more likely to be taken by households that consider themselves at risk (#15), whose household goals are achieved via adaptive action (#13), and whom participate in structured programs to promote action

(#10,11); however, broader community adoption of adaptive action is likely to be limited. Bird *et al.* (2013) argue that the lack of action is a function of the number of constraints that inhibit action compared to factors that enable adaptive change and suggests adaptive behaviour needs to be 'nurtured and facilitated by external agencies' (pg. 88). Similarly, Saman *et al.* (2013) argue incentives are required to promote improvements in housing design and to support the most vulnerable groups (e.g. elderly and low income households). The case-study research further supports these propositions. Despite access to information that details hazard preparation and climate change risks, proactive action has been limited. Similarly, high-investment actions such as installing solar voltaic cells or increasing home insulation have occurred as frequently as low cost actions such as having an emergency response kit or evacuation plan – suggesting incentives (e.g. the Australian national home insulation scheme) address barriers to action for some households.

5. Discussion and conclusion

While empirical research on household adaptation in Australian urban areas is limited, this systematic review and case study research provides insight into actions currently taken and influencing factors. In short, despite the home and property providing important venues for adaptive action, household adaptive action is currently limited. Pro-environmental actions that mitigate climate change and coping strategies to respond to environmental hazards are the dominant response to climate variability and change. Risk perceptions, past experience, homeownership and perceived efficacy (household and action) are associated with action – although these drivers have variable influence depending on the type of action taken. The findings raise several points. First, variance in influencing factors indicates alternate intervention points depending on the action sought. Second, the findings add further weight to the importance of understanding the social processes underpinning adaptation, as barriers arise from perceptions and values (Wolf, 2011). The limited occurrence of adaptive action may be a function of: (i) the efficiency of coping strategies, on the basis that while coping is sufficient adaptation is not necessary (Adger *et al.*, 2004); (ii) limited knowledge of the adaptive options available to households; similarly, (iii) the short history of advocacy for adaptive action compared to pro-environmental action; or (iv) limited capacity to implement action. These points are each discussed.

The discourse of shared responsibility for climate change adaptation is a relatively recent policy position in Australia; most notable in the National Strategy for Disaster Resilience (Council of Australian Governments, 2011), the Australian Governments Position Paper on Adapting to Climate Change (DCCEE, 2010a) and the National Climate Resilience and Adaptation Strategy (Commonwealth of Australia, 2015). However the responsibilities assigned to community members within a shared approach to adaptation are unclear (McLennan and Handmer, 2012, McLennan and Eburn, 2014). More so, households awareness of how they may adapt is limited (Hanson-Easey *et al.*, 2013). Within the home, household occupants can regulate temperature via shading, shutters, and cross-ventilation; protect the home from storms and floods by weatherproofing, elevating entry thresholds and installing protective features such as flash flood doors; and can install water efficiency systems or mitigate climate change via insulation, draft proofing and solar photovoltaic systems (Williams *et al.*, 2012). In the property, occupants can increase shade cover with drought tolerant species, install rainwater harvesting systems, remove non-porous surfaces and improve/maintain garden structures such as gutters and fences (Williams *et al.*, 2012). The finite knowledge of adaptation options available is in contrast to households awareness of actions to mitigate climate change (Whitmarsh *et al.*, 2013), which have been extensively promoted through programs such as Energymark, Livingsmart and Travelsmart. Limited awareness is a barrier to action (Moser and Pike, 2015).

Households also have differing capacities to partake in adaptive action (Middlemiss, 2010). Capacity for adaption in urban areas is a function not only of household characteristics (e.g. income, homeownership); but also governance conditions (e.g. the formal or informal political structures, and institutional factors such as planning and building regulations and incentives) and physical characteristics (e.g. housing age, location, topography, micro-climate and morphology) (Williams *et al.*, 2013). These attributes differ across urban areas and, as reported in the reviewed literature, provide a varying picture of barriers to and opportunities for adaptation. For example, the impact of financial resources on household action was variable. While a commonly reported barrier to adapting to extreme heat, income level was not associated with household action in the case-study communities. This raises two points. First, greater research attention on household adaptation is required to uncover diversity and inform evidence-based policies seeking to promote action at this scale (Porter *et al.*, 2014, Toole *et al.*, 2015). Second, in the case study communities the limited relationship between income level and action is potentially a function of a dominance of coping strategies, which rely on existing resources and assets. However, as the severity of climate change increases, and so too does

the need for more costly adaptive actions (e.g. insulation, water efficiency technologies, green roofs, weatherproof doors, elevating entry thresholds), financial capacity may be more influential in shaping household action. Therefore how equity issues will be addressed both in terms of communication[5] and government intervention (e.g. incentives, market-based instrument, regulation) will be an issue for ongoing consideration.

The results of this study and others (Porter *et al.*, 2014) suggest that autonomous household adaptation is unlikely: yet the Australian government advocates a shared approach to climate adaptation. A shared response is promoted in conjunction with a discourse of self-reliance, in which households are assigned responsibility to prepare their household for the impact of climate change and associated hazards (Allen, 2013, Nalau *et al.*, 2015). The discourse of self-reliance resonates with Australian cultural values depicting Australians as battlers, hard-working, resilient and capable (Allen, 2013, Leitch and Bohensky, 2014). Yet evidence suggests that a narrative of self-reliance reinforces rather than challenges household coping strategies (Elrick-Barr et al, *under review*). So how can the need for external support and promotion of a shared response to adaptation be reconciled? This remains a question for further consideration; however, information appears critical to supporting household adaptation in urban areas. Information requirements include: (i) a greater understanding of the existing dynamics of household adaptation to develop policy cognisant of normative and objective barriers; and (ii) information to support communication strategies, which should target adaptation efficacy, self-efficacy and responsibility. Raising the communities awareness of available adaptive choices and their contribution to vulnerability reduction, clarifying roles and responsibilities and demonstrating the rewards to householders when adaptations are taken early (Porter *et al.*, 2014, Moser and Pike, 2015) will increase household participation in adaptation.

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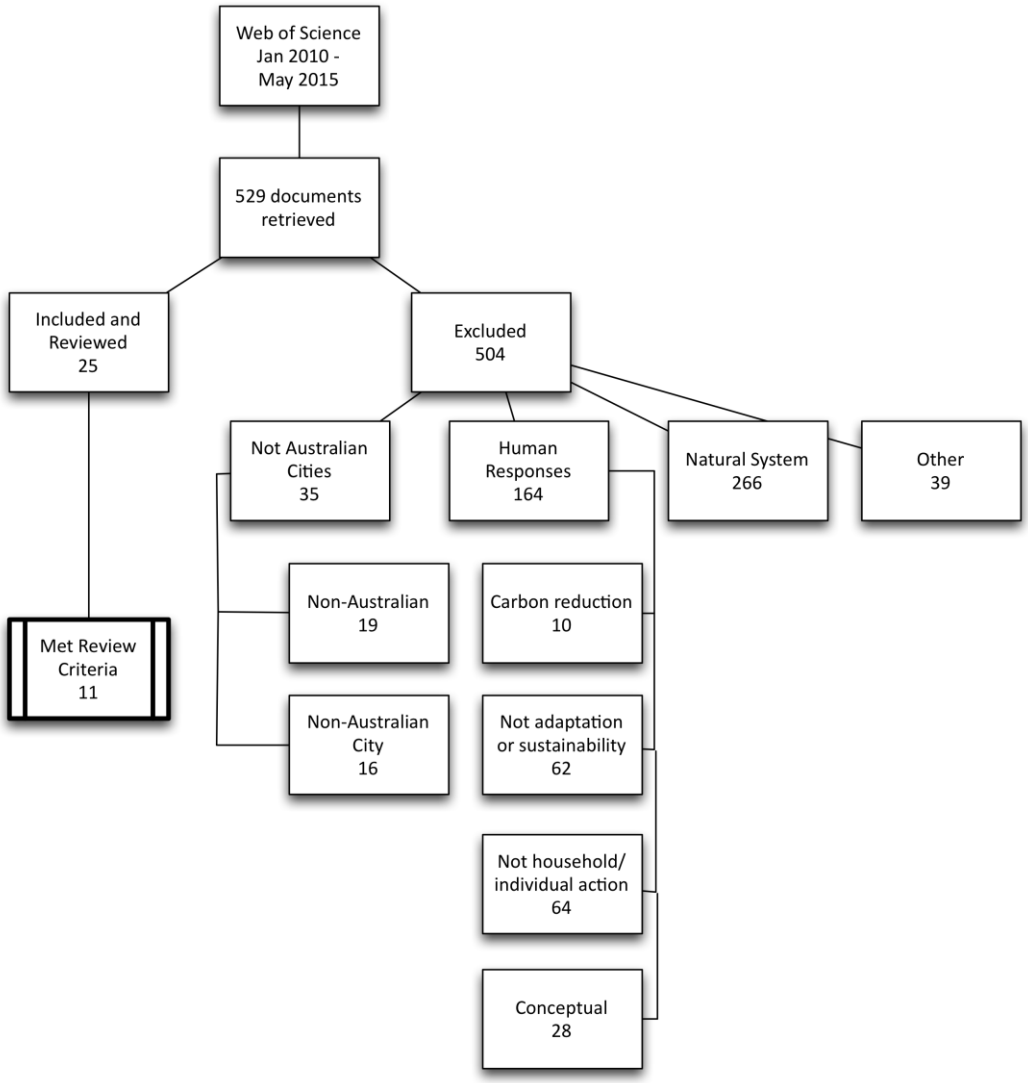

Supplementary Figure 1: Systematic review inclusion/exclusion process

Supplementary Table 1: Drivers and barriers to action for environmental hazards and pro-environmental action, cited in literature review

	Drought	Sea level rise	Flood	Heat	Wildfire	Pro-Enviro
Action Drivers						
Experience/awareness	1		2, 19	6, 18		(no 12), 10
Perceived self-efficacy (including ease)	1	1	19		15	4, 14
Risk perception		1		(no 6)	15	
Belief in climate change						13
Perceived responsibility			19			10
Perceived social norms (including perceived role)				9		4, 10
Positive outcome expectancy			2	6, 10		
Associated with other household goals						13
Emotions					15	13
Behavioural intention						4
Access to information				6		(no 11), 10
Program involvement/group participation						10, 11
Demographics (e.g. income, homeownership, family type)					15	(no 10) 12, 11
Legislation						14
Barriers to Action						
Perceived self-efficacy (including						4

perceived ease)						
Belief in climate change						3,4
Perceived social norms (including perceived role)						3,4
Negative outcome expectancy			2			
Limited knowledge of the risk				19		
Not associated with other household goals						13
Emotions			2			
Demographics (e.g. income, homeownership, family type)			2, 17, 19	8, 5, 6, 9, 18		
Housing design			2	8		
Adaptation efficacy						3

Note: Numbers refer to the paper/report listing the driver or barrier to action, by hazard type. (no) indicates the paper/report stated that the driver/barrier was not an influencing factor in their study.