Assessing Socio-Economic Vulnerability to Climate Change Impacts and Environmental Hazards in New South Wales and Queensland, Australia

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Abstract
This article systematically reviews and synthesises academic, peer-reviewed literature to assess the state of knowledge concerning socio-economic vulnerability to climate change impacts and environmental hazards in New South Wales and Queensland, Australia. It focuses upon empirical research that identifies socio-economic factors associated with vulnerable subpopulations. Using systematic review methods, 35 articles met the inclusion criteria. These articles are analysed according to their general characteristics, the methods used, and the factors reported to be associated with socio-economic vulnerability. This body of evidence reveals that (1) the majority of the knowledge about socio-economic vulnerability in New South Wales and Queensland has only recently emerged; (2) more knowledge has been published about Queensland; and (3) extreme temperature is the most researched environmental hazard. Despite increased research activity over time, the number of factors repeatedly demonstrated to influence socio-economic vulnerability is small. Age, gender, place of residence, and pre-existing illness were the most commonly reported factors, although the influence of these factors upon socio-economic vulnerability is complex. There is scope to extend the empirical research base across a broader range of climate-related hazards and to better link findings from the domains of climate change vulnerability and population health.

KEY WORDS *global change; sensitivity; resource dependency; systematic literature review; indicators*

Introduction

King (2001, 147) reviewed the uses and limitations of socio-economic indicators for assessing community vulnerability to natural hazards. The review was precipitated by his concern that the mere availability of large databases, such as population censuses, was driving the definition and assessment of vulnerability, rather than the information contained therein accurately encapsulating the concept and its dimensions. King identified a number of issues associated with such datasets including problems of scale, the suitability of geographic boundaries used to organise the data, decisions about how indicators

should be weighted, and the ways in which the definition of key concepts influence the selection of indicators.

Since King's review, the literature in which the concept of vulnerability is explored has flourished, particularly in the context of climate change. This literature potentially holds important empirical insights concerning characteristics that are associated with socio-economic vulnerability to climate change impacts and environmental hazards. If this is the case, in situations where the use of primary research methods is impractical, these insights will enable researchers and practitioners to use the information in large databases with more confidence when assessing socio-economic vulnerability to climate change impacts.

The purpose of this article is to critically assess the knowledge that has been generated using inductive research methods about socio-economic vulnerability to environmental and climate-related risks in New South Wales (NSW) and Queensland, Australia. To achieve this, we use systematic literature review methods. Our rationale for this approach is twofold. First, in systematic reviews, the processes for searching the literature and the inclusion and exclusion criteria are clearly defined and reported, meaning that systematic reviews may be used to validate results and then repeated at regular intervals to track research progress (Booth *et al.*, 2012). Second, although systematic reviews are relatively rare outside the medical sciences, in recent years they have been successfully applied to synthesise the rapidly increasing climate change vulnerability and adaptation literatures in other countries (Ford and Pearce, 2010; Furgal *et al.*, 2010; Thompson *et al.*, 2010). We believe that this is the first systematic review of climate change vulnerability literature from the Australian context; thus, we demonstrate the approach and its utility for guiding future research priorities in Australia.

This article is organised as follows: We critique the body of literature reporting the development and/or application of indicator-based approaches used to assess socio-economic vulnerability in NSW and Queensland. Next, we explain the systematic literature review methodology. In the second half of the article, we present our review findings, organised according to the broad characteristics of the reviewed literature, the methods deployed, and the factors that are associated with socio-economic vulnerability. Finally, we identify future research needs and highlight promising avenues by which progress may be achieved.

Assessing vulnerability in NSW and Queensland: indicator-based approaches

Vulnerability can be viewed simply as 'the propensity or predisposition to be adversely affected' (IPCC, 2014, glossary, p. 28). This definition, presented by the Intergovernmental Panel on Climate Change (IPCC) in their fifth assessment, is broader than the often quoted definition from the IPCC's fourth assessment that specifically describes vulnerability as 'a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity' (IPCC, 2007, 883). The IPCC's updated definition may reflect the most recent developments in 'an evolution of conceptual thinking' with regard to the assessment of vulnerability (Füssel and Klein, 2006). Nevertheless, vulnerability is generally understood to comprise a number of interrelated dimensions including (1) exposure, which refers to the physical effects of climatic change; (2) sensitivity, which generally refers to the susceptibility of a system or species to be affected, either adversely or beneficially, by changes in climate; and (3) adaptive capacity, which represents the ability of social systems to adjust, take advantage of, or respond to climatic risks (Adger, 2006; IPCC, 2014).

Attempts to operationalise vulnerability and its allied concepts underpin indicator-based approaches to assess vulnerability (Hinkel, 2011). In NSW and Queensland, since 2000, seven peer-reviewed articles reporting the development and/or application of indicator-based approaches to assess socio-economic vulnerability to climate change or environmental risks have been published (Table 1). In this section, we critically appraise these studies, arguing that attempts to understand the socio-economic vulnerability to climate change impacts in NSW and Queensland using indicator-based approaches may be enhanced through context-specific, empirical evidence of factors shown to be associated with socio-economic vulnerability.

Among the NSW/Queensland studies, the linkages between the concepts that comprise vulnerability and the socio-economic characteristics selected are not always clear. Baum *et al.* (2008) use a 100-year flood model to assess biophysical change and then a composite index to assess social vulnerability, but they do not clearly delineate between sensitivity and adaptive capacity.

Table 1 Factors included in New South Wales/Queensland indicator-based vulnerability assessments.

	Arthurson and Baum (2015)[1]	Roiko *et al.* (2012)	Solangaarachchi *et al.* (2012)	Sano *et al.* (2011)	Nelson *et al.* (2010)[2]	Baum *et al.* (2008)	Granger (2003)
Age	1. Persons 64 years or older	1. Age profiles	1. Median age 2. % over 65 years 3. % of children under 5 years			1. % of people 65 years or older 2. Median age	1. % of people under 5 years 2. % of people over 65 years
Income	2. Low-income individuals 3. Low-income families 4. Median family income 5. Median individual income	2. Median family income 3. Median individual income 4. Median housing loan repayments 5. Median rent	4. % of people with incomes $1–$249 per week 5. % of people with a negative income 6. Median household income 7. Median rent per week 8. Median housing loan repayment per month 9. Median individual income		1. *Financial capital:* capital value of the farm, mean total cash income, access to finance	3. Median household income 4. Median individual income	3. Economic resources
Socio-economic disadvantage		6. Socio-economic advantage/disadvantage index		1. Socio-economic advantage/ disadvantage index			4. Socio-economic advantage/disadvantage index
Household structure and housing	6. Households in public housing 7. Single-parent families	7. One-parent households 8. Lone person households 9. Couples with children 10. Couples with no children 11. Average household size 12. Housing type 13. Housing tenure 14. Projected demand	10. % of rented housing units 11. % of population living alone 12. % of one parent families with child under 15 years 13. % of dwellings that are cooperative, community or church housing units			5. Average household size 6. Average number of people per bedroom 7. % who are widowed	5. Large families 6. Single-parent families 7. Elderly living alone 8. % of households renting 9. Number of detached houses 10. Average house occupancy 11. Number of flats 12. Average flat occupancy 13. Residential ratio
Level of education		15. Education	14. % over 20 years who have a Year 10 education or below		2. *Human capital:* farm operator education, spouse education		14. Education
Employment and occupation	8. Youth unemployment (UEMP) rate 9. Male UEMP rate 10. Male labour force (LF) participation rate 11. Female UEMP rate 12. Female LF participation rate	16. Employment 17. Unemployment rate 18. Labour force 19. Employment sector	15. % employed in service occupations 16. % employed as professionals and managers 17. % of people who did unpaid domestic work less than Five hours per week			8. Male LF participation 9. Female LF participation	15. Unemployment 16. Occupation

Table 1 Continued

	Arthurson and Baum (2015)[1]	Roiko *et al.* (2012)	Solangaarachchi *et al.* (2012)	Sano *et al.* (2011)	Nelson *et al.* (2010)[2]	Baum *et al.* (2008)	Granger (2003)
Ethnicity and migration	13. Indigenous population 14. Recent immigrants to Australia 15. Population who do not speak English well	20. % Aboriginal/Torres Strait Islander	18. % speaking a language other than English at home 19. % of non-Australian citizens 20. % who moved house within the past year 21. % of visitors 22. % who do not speak English well 23. % of migrants from overseas			10. % of people born overseas who arrived in the past five years 11. % of people with poor English skills	17. % of visitors 18. % of new residents
Other	16. Persons requiring assistance with daily activities	21. Population growth 22. Population density 23. Life expectancy	24. % of people who provided unpaid assistance 25. % of volunteers 26. % of housing units with no internet connection 27. % who need special assistance 28. % of females 29. % of dwellings with no vehicle	2. The level of adaptation of the current coastal management framework	3. *Human capital:* self-assessed health 4. *Social capital:* Landcare membership, no. of partners involved in the farm business, internet access 5. *Physical capital:* quantity of plant and machinery relative to other farms, quantity of fixed structures relative to other farms (fences, buildings), average no. of livestock held during the year 6. *Natural capital:* long-term pasture productivity per unit area, no. of dams, remanent vegetation	12. % of residents who require assistance with daily tasks	19. Total population 20. Population density 21. Gender ratio 22. Terminals (e.g. airports) 23. Community facilities 24. % of people with no religious adherence 25. Public safety 26. Commercial ratio 27. Logistic facilities 28. Water supply facilities 29. Power supply facilities 30. Telecommunications facilities 31. Lifeline length 32. Number of cars 33. % of households with no car 34. Road network density

[1]Arthurson and Baum (2015) account for social exclusion/inclusion using a general deprivation index developed in Canada and first applied in Australia by Baum (2004). Here we review Arthurson and Baum (2015), the article in which the index is incorporated into a vulnerability assessment in the context of climate change.

[2]The index for adaptive capacity was originally developed in Nelson *et al.* (2005) and refined in Nelson *et al.* (2007). Here we review Nelson *et al.* (2010), the article in which they apply it to the vulnerability of Australian rural communities to climate variability and change.

Sano *et al.* (2011) clearly identify the ways in which they assess all three dimensions of vulnerability; however, their treatment of adaptive capacity using two characteristics is the most limited of the seven studies. In contrast, Nelson *et al.* (2010) draw the most specific links between the dimensions of vulnerability and the indicators they include. Their index was developed to specifically assess adaptive capacity, but exposure and sensitivity are conflated using measures of historical rainfall, simulated pasture growth, and historical farm income data. In turn, they interpret vulnerability as the intersection between exposure/sensitivity and adaptive capacity. Similarly, Granger (2003), Roiko *et al.* (2012), Solangaarachchi *et al.* (2012), and Arthurson and Baum (2015) do not explicitly address the sensitivity dimension.

Notwithstanding this conceptual and semantic plurality, a number of socio-economic factors used to assess vulnerability are common across the seven articles (Table 1). Age groups considered to be vulnerable (Granger, 2003; Baum *et al.*, 2008; Solangaarachchi *et al.*, 2012; Arthurson and Baum, 2015) or age profiles (Roiko *et al.*, 2012) are used in five articles. Six articles include indicators of the income or financial resources of individuals or households (Baum *et al.*, 2008; Nelson *et al.*, 2010; Roiko *et al.*, 2012; Solangaarachchi *et al.*, 2012; Arthurson and Baum, 2015). Aspects of housing (e.g. dwelling type, tenancy) or household structure are applied in five articles (Granger, 2003; Baum *et al.*, 2008; Roiko *et al.*, 2012; Solangaarachchi *et al.*, 2012; Arthurson and Baum, 2015). The same five articles include indicators associated with employment or occupation, as well as ethnicity or migration. Level of education is incorporated by Roiko *et al.* (2012), Solangaarachchi *et al.* (2012), and Nelson *et al.* (2010), and socio-economic disadvantage is included by Roiko *et al.* (2012), Sano *et al.* (2011), and Granger (2003).

Indicator-based approaches are best suited to studies that aim to identify vulnerable people, regions, or sectors (Hinkel, 2011). In this regard, the NSW/Queensland studies provide valuable insights. Baum *et al.* (2008) conclude that overlaying their biophysical and social vulnerability maps highlights a finer resolution of spatial heterogeneity; that is, areas with the same level of flood exposure may have different vulnerabilities based upon variation in socio-economic characteristics. Similarly, Nelson *et al.* (2010) argue that simply farming in a harsh environment does not necessarily lead to higher levels of vulnerability if people or communities have sufficiently high levels of capacity to cope and adapt with the challenges of their physical environments.

However, the utility of these insights rests upon the selection of the indicators (King, 2001). All of the articles under review here demonstrate a deductive logic, although the authors provide varying levels of justification for the indicators they include in their analysis. Nelson *et al.* (2010) undertake a systematic process to align available Australian agricultural data with the five capitals framework that underpins rural livelihoods analysis (see also Nelson *et al.*, 2007). Other authors draw extensively upon indicators used in international vulnerability studies (Baum *et al.*, 2008; Solangaarachchi *et al.*, 2012; Arthurson and Baum, 2015), rather than cite literature reporting the complex dynamics between socio-economic factors and vulnerability in the Australian context.

Reliance upon non-Australian research seems surprising in light of scholarship that purports that adaptive capacity – and the other dimensions of vulnerability – has 'culture and place-specific characteristics that can be identified only through culture and place-specific research' (Adger, 2003, 400; see also Cutter *et al.*, 2003; Kasperson *et al.*, 2005; Calgaro *et al.*, 2014). Our point here is that the selection and use of indicators to assess socio-economic vulnerability to the impacts of climate change should be informed – at least in part – by empirical research conducted within the socio-economic and geographic contexts of interest. The reliance upon research conducted in non-Australian contexts evident in the NSW/Queensland indicator-based vulnerability assessments suggests that a review of the empirical, inductive socio-economic vulnerability research is a useful complement to the literature.

Tasked with conducting an assessment of socio-economic vulnerability to the impacts of climate change using secondary data sources for six natural resource management regions spanning the Australian states of NSW and Queensland, we sought to establish a set of indicators substantiated by peer-reviewed, empirical research conducted in these jurisdictions. Thus, our geographic focus was narrow, but our search terms were broad in order to capture useful insights reported by researchers who may not necessarily use vulnerability frameworks nor focus upon climate change. The research

Table 2 Inclusion and exclusion criteria used to select the literature reviewed.

Inclusion Criteria	Exclusion Criteria
Phase One: Keyword search	
• January 2000–October 2014	• Before January 2000
• Indexed in Web of Science, Scopus, or Google Scholar	• Not available via Web of Science, Scopus, or Google Scholar
• Reviews and articles	• Duplicated in previous search
Phase Two: Title and abstract review (full text review when required for categorisation)	
• Focuses upon (or includes) socio-economic systems	• Natural systems only (e.g. plants and animals)
• Identifies factors that assess the socio-economic vulnerability of different subpopulations	• Other uses of the search terms (e.g. office climate)
• Reports empirical findings	• Conceptual/theoretical focus
	• Outside geographic area
	• Other (editorials, meetings, abstracts, books, book chapters)
	• Does not identify vulnerabilities of different subpopulations

Table 3 Keywords used to guide the systematic review process.

		Keywords
First tier		Australia
Second tier	AND one of	New South Wales, Queensland
Third tier	AND one of	Vulnerability, exposure, sensitiv*, adapt*, resilience
Fourth tier	AND one of [1]	Global warming, climate change, climate impact*, climate vari*, climate risk*, climate hazard*, climat*, natural hazard*, natural disaster*, environment* risk*, natural threat*

[1]The number of terms was reduced in the Google Scholar search owing to limitations for the number of characters. First-, second-, and third-tier terms were prioritised; fourth-tier terms were reduced.

question that guided our review was 'What are the key determinants of socio-economic vulnerability within NSW and Queensland, Australia?' In the next section, we explain the specific procedures we used to identify the relevant literature.

Methods

A systematic search of the academic, peer-reviewed literature was conducted for the period January 2000–October 2014 and was limited to literature published in English. A two-phase process was used to select the literature for full review. Table 2 presents the inclusion and exclusion criteria used during each phase.

In Phase One, keywords suited to the primary research question were identified and used to search Scopus, Web of Science, and Google Scholar (Table 3). Although the research project that initiated this review focused upon socio-economic vulnerability in the context of natural resource management, the search terms used were broad to capture the breadth of factors associated with socio-economic vulnerability to the impacts of climate and environmental change, broadly defined. The term resilience was included, reflecting the convergence of the vulnerability and resilience literatures (Adger, 2006, 268; Miller *et al.*, 2010).

All sources identified in Scopus or Web of Science were included. The large number of Google Scholar results was managed using similar procedures to those outlined by Furgal *et al.* (2010). Specifically, the first 200 peer-reviewed articles were included. After the 200th peer-reviewed result, each result was inspected for relevance to the current study according to Phase One and Phase Two inclusion/exclusion criteria (Table 2). This process continued until the 700th result in the list, at which time the

search was stopped. The search was stopped at this point because of a declining number of sources that met the full inclusion criteria.[1] These processes resulted in a total of 1004 identified sources: 486 sources from Scopus, 308 sources from Web of Science, and 210 sources from Google Scholar. After removing duplicated sources, 784 sources were submitted to the Phase Two selection process.

Phase Two comprised a title and abstract review to assess the suitability of each source in addressing the research question (Table 2). Specifically, sources needed to identify vulnerable subpopulations using empirical results and report research conducted in NSW or Queensland. Once the set of literature for full review was determined, each source was reviewed for descriptive information (e.g. year of publication, environmental hazard/risk), the methods used, and the socio-economic factors identified as having an association with vulnerability. Figure 1 presents a summary of the documents retrieved during the search.

Results

This section is organised into three parts: (1) an overview of the broad characteristics of the reviewed literature, (2) the methods deployed by researchers, and (3) an overview of the socio-economic factors associated with vulnerable subpopulations identified in the reviewed literature.

Characteristics of the literature

Thirty-five articles were reviewed based upon their contribution to knowledge about differing levels of socio-economic vulnerability to climate change in NSW and Queensland (see Appendix S1). Another 325 articles focused upon human systems but did not evaluate the vulnerability of different population groups. The remaining articles focused exclusively upon natural systems and/or the biophysical impacts of environmental change ($n = 424$).

Over the time period pertaining to this review (1 January 2000–October 2014), the number of articles published has increased, with more than 80% of articles published in the last five years (2010–2014) (Figure 2). First authors were mostly affiliated with either Australian universities (66%) or the Commonwealth Scientific and Industrial Research Organisation (14%). Articles were published in 29 different journals, only one of which published more than two of the included articles (PLOS One).

There is an emphasis upon Queensland-based research ($n = 23$; 66%) compared to NSW-based research ($n = 7$; 20%), while five articles referred to both jurisdictions. More than two-thirds (71%) of included articles specifically examined aspects of socio-economic vulnerability to climate change impacts; the remaining articles focused on vulnerability to environmental risks more broadly. During the review, general organisational categories emerged that were useful for describing current knowledge about socio-economic vulnerability. The articles were categorised according to the primary climate impact or hazard addressed and the sector with which the article was most concerned. Extreme temperature was the most common hazard (45%), followed by climate change in general (14%), storms/cyclones (14%), and drought (11%) (Table 4).

The majority of articles reported studies of population health and well-being ($n = 27$; 78%), 16 of which examined the impacts of extreme temperatures upon population health (e.g. mortality). Three studies focused on the agricultural sector; two were concerned with the vulnerability of particular regions or communities (e.g. Cairns northern beaches); two examined vulnerability within the tourism sector; and one investigated the fisheries sector. The remaining article assessed the implications of limited water availability across 34 economic sectors (Smajgl and Liagre, 2010).[2]

Methods used

The most common methods used to identify vulnerable subpopulations or sectors were statistical models or procedures ($n = 20$, e.g. generalised linear models). Data used were from a range of secondary sources, the most common of which were the Australian Bureau of Statistics and the relevant Queensland government departments (e.g. reported cases of dengue fever from Queensland Health). Biophysical data were typically obtained from the Bureau of Meteorology or the government departments responsible for environmental monitoring (e.g. air pollutant data from the NSW Department of Environment, Climate Change & Water).

Ten articles (29%) reported research conducted using survey instruments. Mixed methods were used in three articles (e.g. focus groups followed by a quantitative survey, in-depth interviews combined with secondary data), while a regional input–output model and a geostatistical approach were each used in one article.

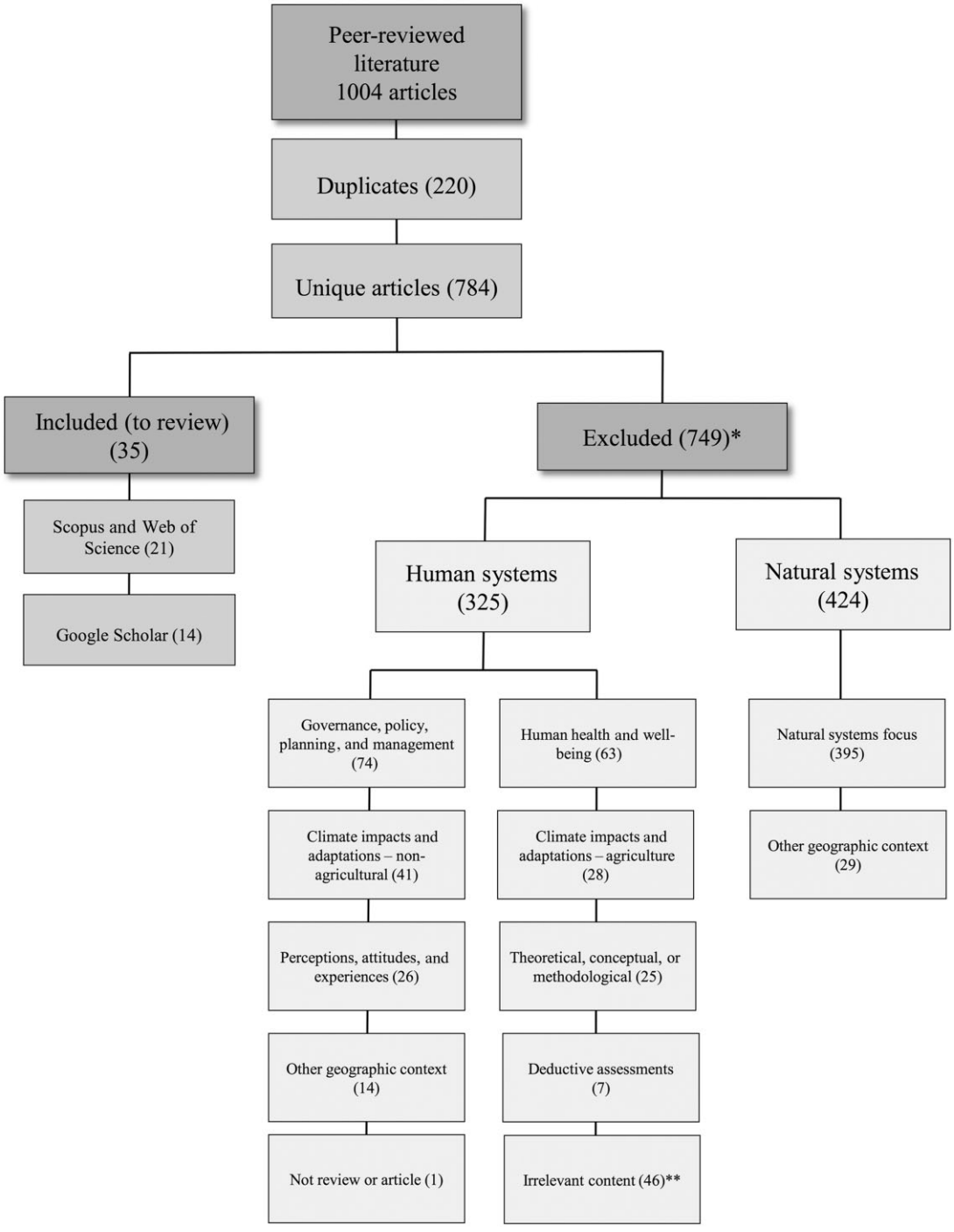

Figure 1 Summary of document selection. *These groupings should not be considered mutually exclusive or decisive. Many articles can be classified to multiple categories. Thus, the groupings provide an indication of the types of articles that were excluded. **The 'irrelevant content' category refers to articles in which search terms were used, but in ways unrelated to environmental and climate-related risks. For example, 'a climate of labour shortages' or 'exposure to the risk of a crash'.

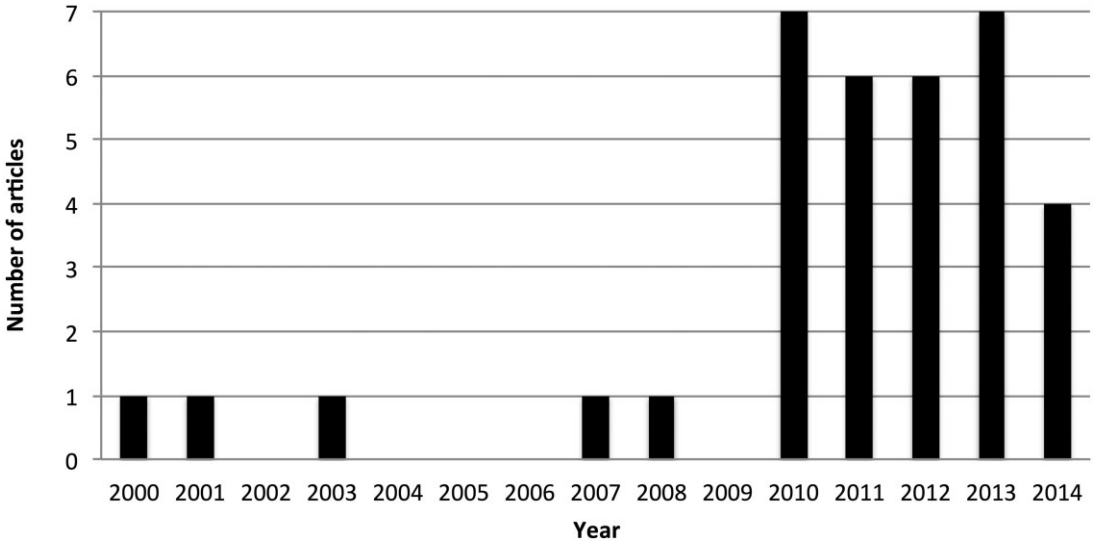

Figure 2 Distribution of the articles according to the date they were published.

Table 4 Articles by climate impact or environmental hazard.

Climate Impact or Environmental Hazard	No. of Articles[1]	Percentage of Total Articles
Climate change focused	*25*	*71%*
Climate change in general	5	14%
Extreme temperature	11	31%
Storms/cyclones	3	9%
Drought	3	9%
Mosquito-borne disease	1	3%
Floods	1	3%
Water scarcity	1	3%
Global change (including climate change)	1	3%
Not climate change focused	*10*	*29%*
Extreme temperature	5	14%
Storms/cyclones	2	6%
Drought	1	3%
Mosquito-borne disease	1	3%
Air pollutants	1	3%

[1]The number of articles represented in this table is greater than 35 because Clemens *et al.* (2013) contained reference to floods and cyclones, so has been categorised twice.

What we know: factors associated with socio-economic vulnerability

Thirty-five factors associated with socio-economic vulnerability and allied concepts were reported in the literature. Fewer than half of these factors ($n = 13$) were reported in more than one article. The most commonly reported factors were age ($n = 20$ articles), gender ($n = 16$), place of residence ($n = 9$), pre-existing illnesses ($n = 9$), socio-economic disadvantage ($n = 3$), and attachment to place ($n = 3$). Table 5 presents the full list of factors revealed in this review.

Age is one of the most commonly used factors to assess socio-economic vulnerability (e.g. Cutter *et al.*, 2003; Rygel *et al.*, 2006). Typically, the influence of age upon vulnerability is interpreted where people at either end of the age spectrum are considered to be most vulnerable (e.g. Granger, 2003; Cutter *et al.*, 2003). However, the interaction between age and socio-economic vulnerability appears more complex. Researchers have reported increased vulnerability to heat-related death with increased age (Yu *et al.*, 2011; Coates *et al.*, 2014). Other researchers have reported (1) no statistically significant relationship between the percentage of elderly people and areas in Sydney with increased mortality on extreme temperature days (Vaneckova *et al.*, 2010); (2) that the relationship between cardiovascular mortality and mean temperature is similar across all age groups (Yu *et al.*, 2011); and (3) age does not significantly modify the risk of hospital admission caused by extreme heat (Khalaj *et al.*, 2010).

Guo *et al.* (2011) reveal further complexities when investigating the influence of temperature changes between consecutive days upon mortality rates in Brisbane. They found that people aged younger than 65 years were more susceptible to temperature increases of 3°C or more

Table 5 Factors associated with socio-economic vulnerability reported in the reviewed articles.

Factor	No. of Articles
1. Age	20
2. Gender	16
3. Place of residence	9
4. Pre-existing illness	9
5. Attachment to place	3
6. Socio-economic disadvantage	3
7. Attitudes	2
8. Business approach	2
9. Dwelling type	2
10. Occupational attachment	2
11. Race/ethnicity	2
12. Social connectedness	2
13. Stage of pregnancy	2
14. Alternative employment opportunities	1
15. Available money	1
16. Business size	1
17. Climate change awareness	1
18. Cyclone awareness education	1
19. Cyclone experience	1
20. Economic sector group	1
21. Employability	1
22. Enterprise age	1
23. Family resilience	1
24. Formal networks	1
25. Human capital	1
26. Income diversity	1
27. Informal networks	1
28. Levels of service infrastructure	1
29. Lifestyle identity	1
30. Marital/relationship status	1
31. Occupation	1
32. Population density	1
33. Proportion of overseas visitors	1
34. Reliance on agriculture	1
35. Use of climate forecasts	1

than other age groups, whereas people aged 65–74 years were more susceptible to temperature decreases of 3°C or more when compared to older and younger people. Similar complexities have been reported among differently aged children (Xu *et al.*, 2014a).

Other environmental risks also appear to impact differently upon people of different ages. Following a cyclone disaster, younger children were more likely to develop severe or very severe post-traumatic distress disorder than older children (McDermott *et al.*, 2012), and Clemens *et al.* (2013) report that adults of working age disproportionately experienced negative emotional, income, and property impacts following the Queensland flood and cyclone disasters. Clemens *et al.* hypothesise their finding reflects the greater likelihood that working age adults participate in the labour force, own income-producing property, have financial dependents, and, therefore, are more exposed to potential impacts than older people.

Gender was the second most cited factor. Articles reporting the health impacts of extreme temperatures show that, historically (1910–1997), males have higher mortality rates than females for both excessive heat and excessive cold (Bi and Walker, 2001). Similarly, males are over-represented in historical statistics for mortality resulting from extreme heat events (1844–2010), but only until the age of 80 years (Coates *et al.*, 2014).

Confounding these studies are insights from research in which the dynamics between heat and mortality are more closely inspected. For example, under certain meteorological conditions, women are at increased risk of mortality when compared to men (Vaneckova *et al.*, 2008; Guo *et al.*, 2011), and in Brisbane, hot and cold temperatures are projected to lead to a higher number of years of life lost among female residents than among male residents (Huang *et al.*, 2012). In the case of children, researchers have reported that boys are more vulnerable to hot and cold temperatures than girls (Xu *et al.*, 2014a). The effect is reversed if emergency department admissions for childhood pneumonia are examined alone (Xu *et al.*, 2014b).

Gender effects have also been associated with the prevalence of mental health issues among children following a cyclone disaster and among adults during prolonged drought conditions. McDermott *et al.* (2010; 2012) conclude that given sufficient exposure and threat perception, all children may be at risk of developing severe or very severe post-traumatic distress disorder following a cyclone disaster, but girls are especially at risk. And Hanigan *et al.* (2012) report that rural males in two age groups (10–29 years and 30–49 years) were at increased risk of suicide during drought, while rural females older than 30 years were at decreased risk. Similar gender differences are evident among incidence rates of mosquito-borne disease (Naish *et al.*, 2011).

The influence of place of residence upon socio-economic vulnerability was addressed at a range of scales including differences between Australian jurisdictions and differences at the sub-state/territory level (e.g. rural versus urban

areas). Negative impacts arising from floods, cyclones, and prolonged drought were amplified for rural residents when compared to urban residents. For example, following the 2010–2011 Queensland natural disasters, rural and remote residents disproportionately experienced negative impacts (Clemens *et al.*, 2013); and during drought, adolescents living in rural/regional Australia reported a significantly higher level of distress than adolescents in the national population (Dean and Stain, 2010). O'Brien *et al.* (2014) report a similar pattern for adults, noting that negative mental health impacts among rural residents seem to only arise from particular drought patterns.

Other large-scale locational differences in susceptibility to environmental risks include higher death rates during extreme heat events in south-eastern Australia than in other parts of the country (Coates *et al.*, 2014). There were higher incidence rates of Barmah Forest virus in coastal Queensland than in inland regions (Naish *et al.*, 2011), and northern Queensland was a high-risk area for locally acquired dengue fever, while southern and eastern Queensland were high-risk areas for overseas-acquired dengue fever (Hu *et al.*, 2012).

The influence of pre-existing illnesses on socio-economic vulnerability is similarly complex. A range of pre-existing illnesses increase the risk of emergency hospital admission (Khalaj *et al.*, 2010) and mortality (Vaneckova *et al.*, 2008). However, not all illnesses are equally susceptible to extreme heat and cold (Vaneckova *et al.*, 2008; Guo *et al.*, 2011; Xu *et al.*, 2014a). Vaneckova *et al.* (2008) report that under certain meteorological conditions, people with circulatory and cerebrovascular diseases are at increased risk of heat-related death, while mortality due to respiratory disease was not significantly higher or lower. In contrast, children with chronic lower respiratory diseases are significantly more at risk of emergency department admission during heatwaves (Xu *et al.*, 2014a).

Pre-existing illnesses modify the risks of extreme temperatures for people in particular age groups. Khalaj *et al.* (2010) report that cerebrovascular disease and cancer significantly increase the risk of emergency hospital admission during extreme heat events for people aged 65+ and 75+, respectively. And Turner *et al.* (2013) found that increased ambulance attendances during heatwaves for cardiovascular and respiratory diseases were particularly pronounced for people aged 65–74 years when compared to other age groups.

Two other studies considered the influence of pre-existing mental illness. People with high levels of anxiety were susceptible to distress resulting from concerns about climate change (Searle and Gow, 2010). In contrast, pre-existing mental health issues were not significantly associated with post-traumatic distress disorder among children following a cyclone disaster (McDermott *et al.*, 2010).

The concept of attachment to place emerged from three articles that develop the concept of resource dependence as a proxy for social systems' sensitivity to climate change (Marshall, 2010; Marshall *et al.*, 2012; 2013). Attachment to place is one of ten components that comprise resource dependency. It describes the level of connection between individuals and the places in which they live/work (see Marshall *et al.*, 2007; Marshall, 2011).

Attachment to place influences vulnerability in quite complex ways. Fishers and tourism operators on the Great Barrier Reef who had higher levels of place attachment displayed higher levels of adaptive capacity (Marshall *et al.*, 2013); similarly, the highest levels of social resilience were associated with Queensland cattle graziers who were also highly attached to place (Marshall, 2010). In turn, these individuals are potentially less vulnerable than people who have lower levels of place attachment. However, higher levels of place attachment among Queensland peanut farmers seem to reduce their capacity for change, thus potentially exacerbating their vulnerability (Marshall *et al.*, 2012). These apparent contradictions may be explained by the ways in which attachment to place influences other components of resource dependency. For example, the highest resilience among cattle graziers was also associated with people who displayed increased interest in using seasonal climate forecasts, viewed themselves as employable elsewhere, adopted a strategic business approach, and were financially secure (Marshall, 2010).

Somewhat surprisingly, socio-economic disadvantage as a determinant of vulnerability only emerged from a small number of studies and the findings were somewhat inconclusive. Although residents in more disadvantaged areas of Queensland disproportionately experienced negative impacts following the 2010–2011 natural disasters (Clemens *et al.*, 2013), the association between areas of socio-economic

disadvantage and heat-related deaths in Sydney was not statistically significant (Vaneckova *et al.*, 2010). However, while there was no association between locally acquired dengue fever and socio-economic advantage/disadvantage, higher rates of overseas-acquired dengue fever were associated with areas of higher socio-economic advantage (Hu *et al.*, 2012).

Discussion: what we do not know and future research directions

A robust knowledge base examining the determinants of socio-economic vulnerability to the impacts of climate and environmental change is only just emerging in NSW and Queensland (largely since 2010). More articles have been published reporting research from Queensland resulting in a relative deficit of articles reporting NSW-based research. There is also an emphasis upon the human health impacts of extreme temperatures, meaning that knowledge about socio-economic vulnerability to other environmental risks is comparatively weak (e.g. sea level rise, storms/cyclones). The emphasis upon extreme temperatures may reflect the ready availability of meteorological and health outcome data. Notwithstanding likely differences in data availability, there remains considerable scope for social scientists to examine socio-economic vulnerability to a broader range of environmental risks of relevance in NSW and Queensland.

Beyond age, gender, place of residence, pre-existing illness – and, to lesser extents, place attachment and socio-economic disadvantage – empirical evidence demonstrating the critical factors that influence socio-economic vulnerability is scattered. Thus, the majority of the factors included in the indicator-based studies reviewed at the beginning of this article are unsubstantiated by NSW- and Queensland-based research. Despite this discrepancy between the high numbers of factors included in these studies when compared to empirical evidence, the findings of this review reveal three important implications for future research.

First, through careful consideration of the climate impact or environmental risk of interest, the factors used to assess vulnerability may be selected in study-specific ways. For example, age is typically included in indicator-based assessments using the percentage of a population that is 65 years or older. This practice is supported by the studies of human health impacts arising from extreme temperatures identified in this review. But the findings from studies of other environmental risks suggest that older people are not always the most vulnerable. In turn, when assessing vulnerability to extreme temperatures, the influence of age may be suitably incorporated using the percentage of the population aged 65 years or older. When assessing socio-economic vulnerability to floods or cyclones, the percentage of the population that is of working age may be more appropriate (Clemens *et al.*, 2013). Of course, such an approach demands that the climate or environmental hazard be clearly specified; that is, selecting factors to assess socio-economic vulnerability to more frequent storm events is less problematic than selecting factors to assess socio-economic vulnerability to climate change, broadly defined.

Second, this review draws attention to meaningful combinations of factors that can enhance socio-economic vulnerability assessments. Hanigan *et al.* (2012) highlight the interaction between age, gender, and drought when they conclude that not all rural males were at increased risk of suicide, only males in particular age groups. Another example is the ways in which pre-existing illnesses create variation in older people's susceptibility to heat and cold (Khalaj *et al.*, 2010; Turner *et al.*, 2013). These examples show that, if combined appropriately, there is scope within vulnerability assessment practice for more sophisticated application and interpretation of the small number of socio-economic factors for which there is the most empirical evidence.

Both of these implications derive from findings reported in the population health and well-being studies included in this review, whose inclusion stems from the broad search terms used. Although these works do not incorporate vulnerability frameworks *per se*, they provide an established body of evidence for strategically selecting factors and unravelling the complex interactions between multiple determinants of socio-economic vulnerability. Thus, we recommend that climate/environmental social scientists explore possibilities for greater integration between their own work and the population health and well-being literature.

The third and final implication relates to conceptual precision and interpretation. The high number of studies that did not incorporate a vulnerability framework (i.e. the population health and well-being studies) prevented a productive analysis of how researchers defined the concept of vulnerability and its associated dimensions (i.e. exposure, adaptive capacity, sensitivity). In

turn, we have not delineated between factors associated with adaptive capacity and those associated with sensitivity. Careful differentiation of these key concepts and their relationships with factors used to assess vulnerability represents another important area for future research.

Despite this lack of conceptual clarity, the findings of this review highlight possibilities for alternative interpretations of how vulnerability is shaped by critical socio-economic factors. Indicator-based approaches typically associate increased age with reduced adaptive capacity arising from social exclusion (i.e. living alone) or limited mobility. However, older age may be a better indicator of people's physical sensitivity to climatic changes. In contrast, other environmental risks may adversely impact the adaptive capacity of other age groups (see Clemens *et al.*, 2013). Similarly, socio-economically disadvantaged areas are typically considered to be more vulnerable than advantaged areas. Hu *et al.*'s (2012) findings about the incidence of overseas-acquired dengue fever demonstrate that some environmental risks demand the focus be placed upon advantaged groups and areas. Although these associations seem logical, the point is that alternative interpretations of how socio-economic characteristics influence a population's vulnerability offer ways to assess vulnerability in more risk- and place-specific ways.

Marshall *et al.*'s (2013) concept of resource dependency is another promising avenue for greater conceptual precision. It is an attempt to operationalise socio-economic sensitivity to climate change. The concept is yet to be extensively applied outside the agricultural sector, but in conjunction with adaptive capacity – which arguably is more developed – resource dependency and its links with vulnerability warrant researchers' attention. In the context of the current article, the concept requires extension so that it may be assessed using secondary data. Detailed conceptual work is undoubtedly required, but insights from Alston (2011) offer some initial guidance. Alston suggests that communities characterised by a high reliance upon the agricultural sector are likely to be more negatively impacted during drought than communities characterised by less reliance upon agriculture. Suitable indicators derived from secondary data could be developed such as the percentage of the labour force employed in agriculture or the percentage contribution of agriculture to gross regional product.

Before concluding this section, we recognise the limitations of this review. First, we focused upon NSW and Queensland. Research from other Australian states and territories may substantially enhance the knowledge base about socio-economic vulnerability to climate change in Australia. Second, the accessibility of suitable search engines and resource constraints led us to focus solely upon the academic, peer-reviewed literature. However, the grey literature may contain useful insights that would also enhance understanding of which factors shape socio-economic vulnerability. Ways to successfully integrate the Australian grey and peer-reviewed literatures are a challenge for researchers seeking to apply systematic review methods in the future.

Conclusion

This article has demonstrated the use of systematic review methods to synthesise the burgeoning and, at times, disparate body of literature addressing vulnerability to climate change impacts and environmental risks in NSW and Queensland. These methods are replicable over time and expandable to larger geographic areas, albeit with slight variations as demanded by future research questions. The benefits that accrue include a rigorous characterisation of the nature and extent of current knowledge and the identification of research gaps (Ford and Pearce, 2010).

The current review has identified that, while there is a strengthening knowledge base focused upon Queensland, the health impacts of extreme temperatures and the ways in which age, gender, place of residence, and pre-existing illness shape vulnerability, knowledge outside of these considerations is piecemeal. This lack of NSW- and Queensland-based evidence offers one explanation for the reliance upon international research evident in the published indicator-based studies reviewed at the beginning of this article. If the research and policy communities are to benefit from using large-scale datasets to assess socio-economic vulnerability when primary research methods are impractical, some strategic direction for future vulnerability research must be set. First, formal climate projections and the places that are likely to be impacted most may be used to determine the suite of climate and environmental changes that should be prioritised. Second, we reiterate Roiko *et al.*'s (2012) call for more cultural- and place-specific data and exploration of the determinants of socio-economic vulnerability through the use of

inductive research methods. While it may be argued that conducting inductive research following natural disasters is fraught with ethical issues, the works of Clemens *et al.* (2013) and McDermott *et al.* (2010; 2012) illustrate that such issues can be overcome. Finally, methods to assess how these critical determinants may change in the future warrant comparable research attention.

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NOTES

1. The first 200 Google Scholar peer-reviewed sources were extracted from the first 276 hits retrieved from the search. One source was included between the 276th and 300th hit; two sources were included between hits 301 and 400; three from between hits 401 and 500; two from hits 501 and 600; and two were included from between the 601st and 700th hits.
2. The number of articles listed here is greater than the number of included articles because Marshall *et al.* (2013) contained reference to the fisheries and tourism sectors.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1 List of 35 articles that met the inclusion criteria for full review.