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Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities

Melissa Parsons [a,c,*], Sonya Glavac [a,c], Peter Hastings [a,c], Graham Marshall [b,c], James McGregor [a,c], Judith McNeill [b,c], Phil Morley [b,c], Ian Reeve [b,c], Richard Stayner [b,c]

[a] Geography and Planning, University of New England, Armidale, NSW, 2350, Australia
[b] Institute for Rural Futures, University of New England, Armidale, NSW, 2350, Australia
[c] Bushfire and Natural Hazards Cooperative Research Centre, Melbourne, Australia

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ABSTRACT

Assessment of disaster resilience using an index is often a key element of natural hazard management and planning. Many assessments have been undertaken worldwide. Emerging from these are a set of seven common properties that should be considered in the design of any disaster resilience assessment: assessment purpose, top-down or bottom-up assessment, assessment scale, conceptual framework, structural design, indicator selection, data analysis and index computation and reporting and interpretation. We introduce the design of an Australian Natural Disaster Resilience Index (ANDRI) according to the common properties of resilience assessment. The ANDRI takes a top-down approach using indicators derived from secondary data with national coverage. The ANDRI is a hierarchical design based on coping and adaptive capacities representing the potential for disaster resilience. Coping capacity is the means by which people or organizations use available resources, skills and opportunities to face adverse consequences that could lead to a disaster. Adaptive capacity is the arrangements and processes that enable adjustment through learning, adaptation and transformation. Coping capacity is divided into themes of social character, economic capital, infrastructure and planning, emergency services, community capital and information and engagement. Adaptive capacity is divided into themes of governance, policy and leadership and social and community engagement. Indicators are collected to determine the status of each theme. As assessments of disaster resilience develop worldwide, reporting of their design as standard practice will track knowledge generation in the field and enhance the relationship between applied disaster resilience assessment and foundational principles of disaster resilience.
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1. Introduction

Academic discourse on disaster resilience is diverse and active, arising partly from disciplinary treatments of resilience concepts. Viewed from a natural science perspective, resilience is a theory for understanding the non-equilibrial dynamics of coupled social-ecological systems, emphasising the adaptability and transformability of social actors in relation to system dynamics, of which natural hazards are a part [39]. In the social sciences, resilience arises from dynamic social, economic, behavioural and protective factors that influence the ability to cope with or prevent stressors, such as natural disasters, that disrupt fundamental expectations of normality [1,48,49,71,80]. Intersecting epistemological debates have subsequently arisen about disaster resilience in relation to themes of vulnerability, risk, governance, sustainability and adaptation (e.g. [4,20,36,71,78]). Such debates are not unexpected given the multi-disciplinary mix of normative and positive interpretations of resilience [67] and the complexity inherent in the post-normal problem of managing natural hazards involving multiple values, multiple stakeholders, incomplete knowledge and high stakes [37,55].

Despite this contested academic discourse, resilience is increasingly the foundation of public policies and programmes in natural hazard and disaster management (e.g. [21,51]). The resilience perspective on natural hazard and disaster management is here to stay [54] but there is little consensus about how to operationalize resilience in practice [4,23]. The practice of disaster resilience is entering what will be a multi-decadal phase of reflective advancement. Applied research is beginning to examine the relationships between disaster resilience and elements of hazard

* Corresponding author at: Geography and Planning, University of New England, Armidale NSW 2350, Australia.
E-mail address: melissa.parsons@une.edu.au (M. Parsons).

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and disaster management such as preparedness, social capital, mitigation and risk perception. However, the policy community tends to be ahead of the research community in the practice and application of resilience concepts [28] because public-policy and programme development often occur on shorter time-scales than research. Some congruence with resilience theory must be maintained as the practice and application of disaster resilience advances, to ensure that foundational principles of resilience are not diluted or, conversely, for practice-based disaster resilience evidence to challenge foundational principles.

Assessment of disaster resilience using an index and component indicators is often a key element of natural hazard management and planning. An index can summarize the state of disaster resilience, thereby providing a tool to identify priorities for improvement and monitor changes in resilience to natural hazards through space and time [51]. However, there is not one standard method to construct a disaster resilience index. An index can be top-down or bottom-up in approach, qualitative or quantitative, use secondary data or collect field-based data, and be measured at a local or national resolution [52]. The construction of an index also requires consideration of options related to the conceptual framework, analysis scale, component indicators and index computation [69]. Given the increasing use of indexes to assess disaster resilience [23], the design of an index should be documented to outline how the assessment relates to foundational principles of resilience (e.g. [26,54]). In this paper we introduce the design of an index to assess the resilience of communities to natural hazards at a large scale across Australia: the Australian Natural Disaster Resilience Index. We start with a brief review of prominent approaches to the assessment of disaster resilience being used worldwide. We then detail the properties that have emerged as being important to the design of a disaster resilience assessment. In the final section we outline the design of the Australian Natural Disaster Resilience Index and show how it aligns with the properties of disaster resilience assessment. The index advances current assessments by including indicators expressing the capacity for learning, adaptation and transformation.

Two clarifications of terminology are required. First, we use the term disaster resilience to mean resilience to natural hazards. We recognise that natural hazard events do not always turn into natural disasters, particularly in communities with high resilience. However, the term disaster resilience is understood by the public in a general sense, and is used worldwide. Second, the focus of the Australian Natural Disaster Resilience Index is resilience, defined as the capacity of communities to prepare for, absorb and recover from natural hazard events, and the capacities of communities to learn, adapt and transform towards resilience. Resilience and vulnerability are related, but not opposite, terms [24]. The vulnerability approach to managing natural hazards arose from observations of the susceptibility and vulnerability of developing countries to natural hazards [56]. The resilience approach to managing natural hazards has emerged more recently and contends that people have agency to prepare, adapt and transform given the presence of social cohesion, community involvement and trust [74]. However, resilience and vulnerability assessment have developed alongside one another and have similar considerations for assessment design.

2. Assessment of disaster resilience – a brief survey of the landscape

Several decades of conceptual and practical development underpin the index-based assessment of disaster resilience [10]. Scores of assessment approaches have been developed worldwide. Cutter [23] identified 27 disaster resilience assessment approaches and evaluated how they differed in focus, spatial orientation, methodology (top down or bottom up) and domain area (characteristics to capacities). The evaluation concluded that there was no dominant approach across these parameters. Beccari [10] identified 106 composite indices for assessing disaster risk, vulnerability or resilience and documented component variables, index construction methods and geographic coverage. The evaluation showed great variation among indices but concluded that more attention needs to be paid to sensitivity and uncertainty analysis, and to ensuring that assessments are high quality and relevant to decision makers. In this section we briefly describe seven prominent disaster resilience, risk or vulnerability assessment approaches. It was not our intent to include the entire population of assessment approaches (readers are referred to Beccari [10], Cutter [23] and Winderl [77] for comprehensive reviews). Rather, we selected well-developed assessment approaches that inform national-scale government programmes or policy because of the similar role our assessment of disaster resilience may play in informing disaster resilience programmes and activities in Australia.

2.1. Index of social vulnerability

Based on a general consensus in the social science literature about the factors that influence social vulnerability, Cutter et al. [25] developed the Social Vulnerability Index (SoVI) to assess vulnerability to environmental hazards in US counties. A set of 42 variables were extracted from US Census data and reduced to explanatory factors representing wealth, age, economic dependence, housing, race, ethnicity and infrastructure characteristics [25]. Factors were added to produce an overall SoVI score and arrayed spatially to show the vulnerability of all US counties relative to each other [25] and through time [27]. The SoVI has also been used as part of integrated multihazard mapping [68].

Further research by Susan Cutter and her colleagues shifted the focus of assessment from vulnerability to resilience. The Disaster Resilience of Place model [26] describes disaster resilience as the place-specific associations between antecedent conditions in social, built and natural environments and the capacity of the community to absorb hazard or disaster impacts using coping responses [26]. The antecedent conditions for disaster resilience were assessed using indicators of social resilience, economic resilience, institutional resilience, infrastructure resilience and community capital, derived from archival data [28]. Indicators were combined to produce an overall community resilience score and arrayed spatially to show the vulnerability of Florida counties relative to each other [28].

Also in Florida, Burton [17] assessed disaster resilience using indicators of social resilience, economic resilience, institutional resilience, infrastructure resilience, community capital and environmental resilience. This work builds on Cutter et al. [28] by including environmental resilience, but also by using a different composition of indicators. Burton [17] validated indicators against Hurricane Katrina recovery data before deriving a comparative index of disaster resilience in the gulf coast counties. The validation of indicators showed that some variables were more strongly associated with actual recovery than others and thus were better proxies of resilience.

2.2. The resilience scorecard approach

The resilience scorecard approach is a toolkit for communities to assess their disaster resilience. Disaster resilience is assessed using a set of questions related to community connectedness, available resources, planning and procedures and risk and vulnerability [6]. The questions are arrayed as a scorecard and answered using census data, emergency service resources, risk assessments, policy and planning resources and household self-assessment [72]. Questions are scored using a Likert scale and added to form an overall assessment of disaster resilience in the community in which the survey was undertaken. The questions were developed from evidence of the general factors influencing disaster resilience, but are worded in a user-friendly manner aimed at engaging local community and local government understanding about their level of disaster resilience [6].

2.3. The World Risk Index

The World Risk Index is a global-scale assessment of natural hazard and climate change risk and vulnerability. The World Risk Index is derived from indicators of exposure to hazards (including sea level rise), susceptibility, coping capacity and adaptive capacity [76]. The Risk Index of each country can be reported as an overall risk index, or by individual categories of exposure, susceptibility, coping capacity and adaptive capacity [73]. Reporting of individual categories is important because the same overall risk score of two countries can be made up of different values of individual categories [73]. The index is calculated using available global or national data from 171 countries, allowing countries to be ranked relative to each other [76], and is recalculated each year.

2.4. The MOVE framework

The MOVE approach to disaster vulnerability assessment was developed in Europe [15]. It comprises a generic framework for integrated vulnerability assessment, procedural steps for conducting a vulnerability assessment and a tool box of assessment methods that includes indicators of vulnerability [15,34]. Indicators are specific to each vulnerability assessment, but generally include aspects of exposure and physical risk, social fragility, economic disruption, capacity to cope, institutional arrangements, environmental status and demographics [34].

2.5. The Prevalent Vulnerability Index

The Prevalent Vulnerability Index (PVI) assesses predominant disaster vulnerability conditions by measuring exposure in prone areas, socioeconomic fragility and lack of social resilience across countries in Central and South America [18]. The PVI of each country can be reported as an overall index, or by individual categories of exposure and susceptibility, socioeconomic fragility and lack of resilience [19]. The PVI is calculated using available national data, allowing countries to be ranked relative to each other [19]. The Prevalent Vulnerability Index is part of a holistic system of indicators – the IDB-IDEA programme – that includes the Disaster Deficit Index, the Local Disaster Index and the Risk Management Index [19].

2.6. The Communities Advancing Resilience Toolkit (CART)

The Communities Advancing Resilience Toolkit (CART) is a holistic programme for measuring community resilience and engaging communities to explore and promote actions to enhance resilience [62]. Four domains form the basis for resilience description and community capacity building: connection and caring; resources; transformative potential; and, disaster management. Resilience is assessed using a questionnaire based survey of individuals, where survey results form a community profile of disaster resilience [61]. Information about resilience gained from the assessment is then used as baseline information in community-driven group processes, planning exercises and actions to enhance community resilience [62].

2.7. The capacities approach

Norris et al. [54] proposed that disaster resilience emerges from a set of four networked adaptive capacities. In this approach, resilience is seen as a process rather than an outcome, and adaptive capacities are the dynamic resources influencing community and population wellness [54]. Social capital comprises the factors that maintain and sustain community health, including social support, social structures and linkages, community bonds and commitments and sense of place [54]. Economic development comprises the factors supporting the level of economic resources available to communities, including resource volume, resource diversity and resource equity [54]. Community competence embodies the factors that allow communities to learn and work together flexibly to solve problems, including collective action and decision-making, trust, empowerment and partnerships [54]. Information and communication refers to the creation of common meanings and the opportunities for articulating needs, views and attitudes, including narratives and the infrastructure of public information systems [54]. The interactions between these four dynamic capacities shape the disaster readiness and post-disaster recovery of communities [54].

Disaster resilience is observable through quantitative or qualitative measurement of capacities. Sherrieb et al. [65] conducted a pilot assessment of community resilience in Mississippi counties based on the economic development and social capital adaptive capacities of Norris et al. [54]. Indicators of economic development (e.g. employment, income, tax revenue, income equity, occupational diversity, urban influence) and social capital (e.g. household structure, civic organizations, voter participation, religion, migration and crime) were derived from archival population-level data and combined to form an index of community resilience. This index was arrayed spatially to show the community resilience of Mississippi counties relative to each other [65]. To our knowledge, the index of community resilience based on adaptive capacities has not been applied or developed further in the context of disaster management although through common authorship it is precursor work to the CART programme.

In summary, the assessments differ in several aspects. The focus of an assessment may be resilience (e.g. CART, resilience scorecard approach, capacities approach), vulnerability (e.g. SoVI, PVI, MOVE framework) or risk (e.g. World Risk Index). They may employ top-down (e.g. SoVI, World Risk Index) or bottom-up (e.g. resilience scorecard approach, CART) data collection methods. An assessment may be local (e.g. resilience scorecard approach), national (e.g. SoVI) or international (e.g. PVI, World Risk Index) in application. Each assessment has a unique purpose, including supporting communities to enhance disaster resilience (e.g. resilience scorecard approach, CART) and comparative assessment of different locations using standardized data (e.g. SoVI, World Risk Index). These differences between approaches are commensurate with similar review exercises (e.g. [10,23]) and further highlight the heterogeneous landscape that has developed in the field of disaster resilience assessment over several decades.

3. Properties for the design of disaster resilience assessments

The previous section highlighted the heterogeneity that exists in the developing field of disaster resilience assessment. However, the heterogeneity associated with these approaches suggests that common properties should be considered in the design of assessments of disaster resilience using an index [69]. Common properties set the scope of any disaster resilience assessment and are influenced by conceptual, technical and practical considerations. In this section we outline the common properties that should be considered when designing an assessment of disaster resilience, and its component index and indicators. These properties are derived largely from Eric Tate's stages and options for social vulnerability index construction [69]. Assessment purpose [23], top-down versus bottom-up assessment [23] and index reporting [10] are our additions.

3.1. Assessment purpose

In broad terms, assessment refers to a qualitative or quantitative process of evaluating the status of some phenomenon of interest. Assessment can be driven by different concerns and conducted for different purposes including (1) to gauge or audit the state of a system at one point in time or over time, (2) to assess whether regulated performance criteria have been exceeded, (3) to detect and assess the impacts of human generated disturbance or (4) to assess the responses to mitigation, restoration or policy implementation efforts [30]. Assessment can also be undertaken to predict or forecast future trends in a phenomenon of interest in response to the application of treatments. Information arising from assessment is usually fed back into decision or policy making processes to highlight potential problem areas, approve regulation conditions, reform policy, prioritize support, guide research and development, establish programmes and set organizational goals. Thus, the purpose of any resilience assessment needs to be defined at the outset because purpose influences the design, content and computation of an index.

3.2. Top-down or bottom-up assessment

A key distinction is made between bottom-up and top-down assessment approaches. Bottom-up approaches (e.g. [6,62]) use community surveys and stakeholder interviews to directly derive indicators and assess resilience [52]. Top-down approaches (e.g. [25,73]) use existing secondary data, such as census or economic data, to indirectly derive proxy indicators and assess resilience [52]. A bottom-up resilience assessment can theoretically be undertaken at a national scale and a top-down resilience assessment at a local scale. However, there is generally an inverse relationship between scale and the logistics of community involvement, so that bottom-up assessments tend to be undertaken at a local level and top-down assessments at a State, National or International level [52]. Bottom-up and top-down assessments may also be hazard specific or general to all hazards [52]. The choice of top-down or bottom-up assessment is an important consideration because it determines the degree of community involvement in the assessment process, influences the cost and spatial extent of the assessment [52] and the ability to compare across units of analysis using standardised data [23]. It is also important to understand the boundaries of each approach, because both have a level of spatial or conceptual limitation beyond which conclusions about resilience are no longer valid. However, the relationship between the outputs of top-down and bottom-up resilience assessments have not yet been well researched.

3.3. Assessment scale

Extent is the overall area encompassed by a study and grain is the size of the sampling units used in a study [75]. Larger spatial scales are assessed by increasing the extent of the study and smaller spatial scales are assessed by making the study fine grained. Despite the apparent simplicity of this concept, trade-offs need to be made in the design of an assessment. If the spatial extent of a study is large, the sampling will be prohibitively expensive unless the grain is relatively coarse, and any study with a fine grain must of necessity have a narrow extent [5]. This is why bottom-up assessments of disaster resilience tend to be local in extent, with data derived from fine-grained survey instruments (e.g. [6]), whereas top-down approaches tend to be large in extent, using secondary data with a pre-determined grain (e.g. [28]). Consideration of the spatial grain and extent of a resilience assessment ensures that the processes influencing the selected dimensions of resilience are captured in the assessment at an appropriate spatial scale.

Dimensions of resilience are also dynamic through time [27]. Assessment design thus needs to consider the temporal scale of the assessment in relation to the purpose of the assessment. Will the assessment be an audit at one point in time or conducted repeatedly to determine trends in resilience in relation to a baseline condition (e.g. [27,28])? The temporal domain within which an assessment is conducted should be reported to ensure that interpretations of resilience are not taken outside their temporal boundary.

3.4. Conceptual framework

The underlying conceptual framework is the philosophical justification of the resilience assessment approach. In short, the conceptual framework justifies the dimensions of what the index is intended to measure [59,69,77]. For example, the Disaster Resilience of Place (DROP) model [26] underpins the Index of Social Vulnerability. A conceptual framework can be created, or extended from an existing framework. Regardless of its origin the conceptual framework is an important step in constructing a resilience assessment because it positions the assessment in the context of the field of disaster resilience, and guides the scope and treatment of assessment elements. The conceptual framework should be published before, or in conjunction with, the assessment results (e.g. [15,27,58]) although some assessments of disaster resilience are conducted and reported without reference to a guiding conceptual framework.

3.5. Structural design

Structural design is the arrangement of indicators within an index-based assessment of disaster resilience (e.g. [10]). The structural design of a resilience assessment index can be deductive, hierarchical or inductive [69]. Deductive designs contain fewer than ten indicators, which are normalized and aggregated to an index. Hierarchical designs employ around twenty indicators that are separated into themes sharing the same underlying dimension. A sub-index is generated for each theme and the sub-indices aggregated to an index. Inductive designs begin with a large set of indicators which undergo dimensional reduction, either with principal components analysis or factor analysis. The factors are aggregated to form the index. Consideration of structural design is important because different structural designs are sensitive to data computation elements. Deductive designs are sensitive to data transformation, hierarchical designs to indicator weighting and inductive designs to the indicator set and scale of analysis [69]. Deductive and hierarchical designs also report data directly, whereas inductive designs transform data into components which may not be readily interpretable.

3.6. Indicator selection

An indicator is a quantitative measure ‘intended to represent a characteristic of a system of interest’ [69]. An indicator can be composed of one variable, or many. In the latter case it is known as a composite indicator or index [59,69]. An index responds directionally according to the behaviour of the system [17] and can be arrayed along a continuum of good to poor status. Indicators are

Table 1
Generalized criteria for indicator selection. Compiled from [11,14,16,46,77].

Criteria for indictor selection	Requirements
1. The indicator reflects a justifiable element of natural hazard resilience	• The relationship between the indicator and natural hazard resilience has been verified in the academic/professional literature
2. The indicator can track change and variability in natural hazard resilience	• Change in the indicator can be determined and associated with change in resilience spatially and temporally
3. The indicator is relevant to the scale(s) of assessment	• The indicator aligns with the scale at which the assessment is undertaken. There may be a requirement for an indicator to remain valid across scales (e.g. local to national).
4. The indicator is measurable and readily interpretable	• The indicator is specific and precisely defined. • The indicator is quantifiable and spatially referenced • The indicator is easy to define, understand and communicate
5. The measurement method for the indicator is robust	• Measurement is reliable (and verifiable) and representative of reality • Measurement occurs regularly enough for the purpose • Measurement is methodologically sound
6. The indicator is achievable – data are available, accessible and cost effective	• Data are available at the required scales across most of the study area • Data are readily available from secondary sources • Data can be accessed within the cost and resource framework

based on normative understandings of relationships between a variable and a broader thematic concept, with varying degrees of empirical support [14,46]. The evidence supporting these relationships can be literature-based logical plausibility (e.g. [25]) or causal validation (direct observation or indirect structural equation modelling) of the relationship between an indicator and the thematic dimension it represents (e.g. [17,60]). The use of logical plausibility is presently most common in disaster resilience assessment because causal validation specifying the association between an indicator and disaster resilience or vulnerability is only recently attracting research focus [63].

Selecting indicators, and the variables that make up indicators, is both an art and a science. An indicator always implies that a relationship exists between the indicator and a latent construct representing some aspect of resilience. Thus, the process of indicator selection is also coupled with the purpose, framework, design and interpretation of the index. While there will always be trade-offs between indicator specificity, data availability, cost effectiveness and sensitivity [14,77], the selection of indicators can be guided by criteria that help to bound large sets of potential indicators (Table 1). The use of indicator selection criteria minimizes potential sources of uncertainty in the interpretation of disaster resilience arising from the types of indicators included in computation.

3.7. Data analysis and index computation

There are many data analysis and computation elements to consider in the construction of a resilience index, including measurement error, transformation, normalization, data reduction, factor retention, weighting and indicator aggregation [69]. Index construction also involves geographical adjustments (such as spatial aggregation or disaggregation), indicator adjustments (such as imputation of missing values and indicator reversal to align with resilience), many of which are directed towards reducing the undesirable effects of the skewness and kurtosis (types of departure from normality) of indicators on composite indices [59]. Analysis and computation choices ultimately influence the relative rankings of entities [69]. Thus, sensitivity and uncertainty analysis must be built into index construction to evaluate and report the reliability of index based assessments of resilience under different computational choices. Sensitivity analysis examines how each individual source of computation choice contributes to the output variance and uncertainty analysis examines how computation of the input factors propagates through an index structure [64]. Methods for undertaking sensitivity and uncertainty analyses are well developed (see reviews by OECD [59] and Saisana et al. [64]).

3.8. Reporting and interpretation

Reporting is a key property of resilience assessment because it interprets and communicates findings in relation to the purpose of the assessment. Reporting of a resilience index generally involves a spatially explicit depiction of the value of an index or component themes (e.g. [25,73]), and may be accompanied by tools that allow spatial interrogation of the index, or sophisticated graphical representation of index outputs [10]. Resilience assessments are also used to support policy and decision making and thus, reporting should help to construct narratives for lay and literate audiences [59].

4. A framework for assessing disaster resilience in Australia

Like many countries Australia is faced with the potential for increasing losses from natural hazard events. The National Strategy for Disaster Resilience was adopted by all Australian States and Territories in 2011 [21]. The strategy recognises that disaster resilience is not just the domain of emergency service agencies, but is a shared responsibility among governments, individuals, communities and businesses [21]. Action-based disaster-resilience planning strengthens local capacity and capability, with emphasis on community engagement and a better understanding of the diversity, needs, strengths and vulnerabilities within communities (e.g. [8,21,32]). Part of operationalizing disaster resilience in Australia is assessing the current state of disaster resilience: it is within this context that the Australian Natural Disaster Resilience Index (ANDRI) is being developed. This section outlines the design of the Australian assessment according to the common properties of resilience assessment outlined in the previous section. The data analysis and computation properties are not addressed in this paper.

4.1. Purpose of the ANDRI assessment

The purpose of the ANDRI assessment is to audit the state of disaster resilience in Australia at one point in time. The ANDRI is not designed to assess regulated performance criteria. The assessment results will be reported as a State of Disaster Resilience Report. Government and emergency service agencies have been involved in the design of the assessment to ensure that the outputs can inform strategic resilience directions and input to macro-level policy, strategic planning, community planning and community engagement activities at National and State-government levels, and by other organizations such as NGOs. Thus, a key part of

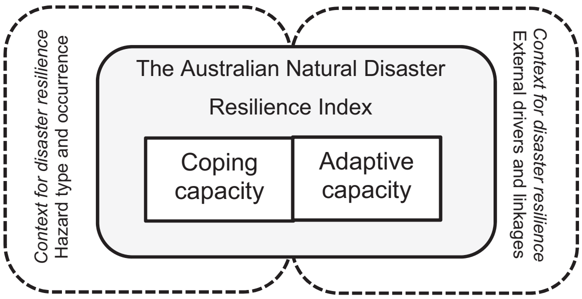

Fig. 1. Conceptual elements of the Australian Natural Disaster Resilience Index. Coping and adaptive capacities form the basis for assessment of disaster resilience, where coping capacities are the means by which people or organizations use available resources, skills and opportunities to face adverse consequences that could lead to a disaster and adaptive capacities are the arrangements and processes that enable adjustment through learning, adaptation and transformation. Resilience assessment sits within a context of the occurrence of different natural hazard types and external drivers and linkages (dashed lines) but these factors are not assessed as part of the index.

designing the ANDRI assessment is consideration of how it will be applied as a planning tool. Once an initial resilience assessment is completed, it will form the baseline against which changes in resilience can be tracked through time (e.g. [27]).

4.2. *Type of assessment and assessment scale*

The ANDRI takes a top-down assessment approach. The index is a national-level assessment and given limited resources, it is not possible to undertake a bottom-up community survey across the whole of the nation. Thus, the ANDRI applies a top-down assessment approach using existing secondary data to form indicators. The assessment will provide a nationally-standardised assessment of disaster resilience in Australia, with continuous spatial coverage of the entire country. The ANDRI does not seek to provide detailed community-led assessment of resilience in a local area, which is the domain of bottom up assessment. Commensurate with the large-scale national focus the grain of the assessment, where possible, is the Statistical Area 2 (SA2) level of the Australian Bureau of Statistics [7]. The SA2 level was selected because it is most representative of Australian neighborhoods/suburbs and because it is the smallest level of the Australian Statistical Geographical Standard for which estimated resident population, health statistics and vital statistics are all available [7]. At the time of the last Census in 2011 there were 2214 SA2s across Australia. The SA2s have an average population of around 10,000 people but can be as small as 3000 and as large as 25,000 people, depending on the remoteness of the SA2. Not all of the indicators will be available at SA2 level because many are a derivation of the levels at which policy is administered or statistics are reported (e.g. States, local government areas, regions, police districts). Where this occurs in the ANDRI, data will be disaggregated to the SA2 level. The mixed spatial resolution of indicators is a common issue in top-down resilience assessment and particularly influences outputs from inductive index designs [69]. However, mixed spatial resolution data should not necessarily limit the design of an index in relation to the conceptual framework, provided that its influence on index computation and resilience interpretation is reported alongside assessment results.

4.3. *Conceptual framework*

The conceptual framework for the ANDRI blends existing definitions, models and disciplinary influences on disaster resilience. It is not the intent to review disaster resilience here: many disaster resilience definitions and epistemologies exist and have been reviewed extensively (e.g. [12,20,47,54,78,79]). Three aspects of resilience are common among disaster resilience definitions and epistemologies: the ability to absorb or accommodate the effects of an external disturbance or stressor event [1]; the ability to recover and return to a functioning state or to persist following an event [9,20,54]; and, the capacity to learn, adapt or transform [12,51]. Assessment of disaster resilience therefore requires consideration of the capacities (the resources) within a system that influence absorbing and persisting in the presence of natural hazards and which enable learning, adjustment and transformation. In the ANDRI, disaster resilience is defined as the capacity of communities to prepare for, absorb and recover from natural hazard events, and the capacities of communities to learn, adapt and transform towards resilience.

Following from the definition of resilience, the ANDRI uses a capacities approach to assess disaster resilience. Capacities assess the potential for disaster resilience within the system of interest, rather than the actual realization of disaster resilience in relation to a particular natural hazard event (e.g. [54]). However, information about the latter can be used to validate the former (e.g. [17]). Prominent top-down assessments of disaster resilience have taken the capacities approach and focus on assessing the potential for disaster resilience using indicators of component capacities ([25,73]).

The ANDRI assessment of disaster resilience distinguishes two sets of capacities: coping capacities and adaptive capacities (Fig. 1). There is debate about the meaning of coping and adaptation as descriptors of capacities. These debates are largely about whether coping and adaptation are immediate reactions in response to a natural hazard event, or emerge from social processes that develop the capacities required to anticipate and withstand unpredictable adverse conditions [12,80]. The ANDRI assessment takes the latter view because policy emphasis is on building disaster resilience through understanding natural hazards as unpredictable but inevitable shocks in social systems. Coping capacities are defined as the means by which people or organizations use available resources, skills and opportunities to face adverse consequences that could lead to a disaster [43]. Coping capacity captures the characteristics of a system that allow it to anticipate, act, achieve goals and manage resources [80] or which are associated with absorptive capacity and mobilization when a natural hazard event occurs [26,71]. In a practical sense, coping capacity relates to the factors influencing the ability of a community to prepare for, absorb and recover from a natural hazard event.

Adaptation is the decision making process and actions undertaken to adjust to current or future predicted change [53]. Adaptation involves deliberate incremental and transformational change across social, government and economic systems. The capacities which enable adaptation are related to the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups [35]. Adaptive capacity has been identified as a key component of disaster resilience [43,57,71] but is rarely included in disaster resilience assessments (see [15,73] for exceptions). Although it has been a core theme of the theoretical literature on disaster resilience [33], adaptive capacity and the agency of societies to transform and learn in the face of natural hazards is a newer concept in resilience assessment. For example, Cutter et al. [28] did not attempt to include adaptive capacity indicators, despite adaptive capacity being part of the DROP Model [26]. The ANDRI assessment includes adaptive capacity. Adaptive capacity is defined as the arrangements and processes that enable adjustment through learning, adaptation and transformation. Adaptive capacity differs from coping capacity in that adaptive capacity focuses on the potential for the facilitation of adaptation by governance, institutional, management and social

Table 2
Themes of coping and adaptive capacity within the Australian Natural Disaster Resilience Index. The right hand column summarizes the relationships between the theme and natural hazard resilience.

Theme definition	**Description of theme**	**Relationship of theme to natural hazard resilience**
Coping capacity		
Social character The social characteristics of the community.	• Represents the social and demographic factors that influence the ability to prepare for and recover from a natural hazard event.	• Gender, age, disability, health, household size and structure, language, literacy, education and employment influence abilities to build disaster resilience [50,70].
Economic capital The economic characteristics of the community.	• Represents the economic factors that influence the ability to prepare for and recover from a natural hazard event.	• Access to economic capital may be a barrier to resilience [13]. • Losses from natural hazards may increase with greater wealth, but increased potential for loss can also be a motivation for mitigation. • Economic capital often supports healthy social capital [70].
Infrastructure and planning The presence of legislation, plans, structures or codes to protect infrastructure.	• Represents preparation for natural hazard events using strategies of mitigation or planning or risk management.	• Considered siting and planning of infrastructure is an important element of hazard mitigation. Multiple levels of government are involved in the planning process [22,45]. • Planners can be agents of change in building disaster resilience [66].
Emergency services The presence of emergency services and disaster response plans.	• Represents the potential to respond to a natural hazard event.	• Emergency response capabilities and systems support resilience through the PPRR cycle [41].
Community capital The cohesion and connectedness of the community.	• Represents the features of a community that facilitate coordination and cooperation for mutual benefit.	• Social networks assist community recovery following disaster [2]. • Bonding, bridging and linking social capital can enhance solutions to collective action problems that arise following natural disasters [3].
Information and engagement Availability and accessibility of natural hazard information and community engagement to encourage risk awareness.	• Represents the relationship between communities and information, the uptake of information about risks and the knowledge required for preparation and self-reliance.	• Emergency management community engagement comprises different approaches including information, participation, consultation, collaboration and empowerment. • Community engagement is a vehicle of public participation in decision making about natural hazards [42].
Adaptive capacity		
Governance, policy and leadership The capacity within government agencies to learn, adapt and transform.	• Represents the flexibility within organizations to adaptively learn, review and adjust policies and procedures, or to transform organizational practices.	• Effective response to natural hazard events can be facilitated by long term design efforts in public leadership [20,71]. • Transformative adaptation requires altering fundamental value systems, regulatory or bureaucratic regimes associated with natural hazard management [57]. • Collaborative learning facilitates innovation and opportunity for feedback and iterative management [12,38].
Social and community engagement The capacity within communities to learn, adapt and transform.	• Represents the social enablers within communities for engagement, learning, adaptation and transformation.	• Bonding, bridging and linking social capital can enhance solutions to collective action problems that arise following natural disasters [3]. • Cooperation and trust are essential to building disaster resilience and arise partly through social mechanisms including social capital [35,38]. • Behavioural change has a social and cultural context [29,31].

arrangements and processes [15,40,44] whereas coping capacity focuses on the capacities of communities to anticipate and respond to hazards.

The ANDRI assesses coping and adaptive capacity only (Fig. 1). However, there are two factors which contextualise the application of the ANDRI assessment in policy and strategic planning. First, the ANDRI assessment takes an all-natural-hazard approach and assumes that the coping and adaptive capacities enable resilience to all types of natural hazards. The types of natural hazards occurring in a location are not considered as part of the ANDRI (Fig. 1). The intent is that spatial outputs from the ANDRI can be overlaid onto existing natural hazard occurrence maps to examine the intersection between prevailing natural hazards and the capacities for disaster resilience. Second, external drivers and linkages, such as demographic and economic trends, regional development and environmental change also influence the application of the index in policy and strategic planning, but are not included in the ANDRI assessment (Fig. 1).

4.4. Structural design

The Australian Natural Disaster Resilience Index assessment has a hierarchical structure. The first level of the hierarchy comprises coping and adaptive capacity dimensions (Table 2). Nested within this are themes that express the elements of coping and adaptive capacity (Table 2). These themes are consistent with the commonly-applied capacities of disaster resilience identified by Cutter [23] as emergency management, social capital, community functions, institutional capacity, communication/information and planning. The relevance of these themes in capturing the influences on disaster resilience in Australia were also determined in consultation with government and emergency service agencies.

Table 3
Indicators comprising the coping and adaptive capacity themes in the Australian Natural Disaster Resilience Index. Themes are detailed in Table 2.

Theme[a]	Indicator dimension	Variables[b]
Coping capacity		
Social character	Immigration	Population arrived in Australia 2001 onwards
	Internal migration	Households with all or some residents not present one year ago
	Language proficiency	Population speaks English not well or not at all
	Need for assistance	Population with a core activity need for assistance
	Family composition	One parent families
		Households with children
	Household composition	Lone person households
		Group households
	Sex	Sex ratio
	Age	Population aged over 75
		Population aged under 15
		Median age of persons
	Education	Ratio of certificate/postgraduate to high school education
	Employment and occupation	Population unemployed
		Population not in the labour force
		Population managers and professionals
Economic capital	Home and car ownership	Population owning home outright
		Population owning home with a mortgage
		Population renting
		Median rent
		Income to mortgage differential
		Car ownership
	Income	Median total family income
		Low income residents
	Employment	Single sector employment dependence
		Businesses employing >20 people
		Retail and commercial establishments
	Economy	Economic diversity index
		Population growth or decline
Infrastructure and planning	Dwelling type	Caravan, marina, manufactured home, retirement village dwellings
	Building codes	Buildings constructed after 1980
	Local government planning	Local government disaster management planning
		Local government land use planning
		Local government financial status
Emergency services	Health response workforce	Total medical practitioners
		Total registered nurses
		Hospital beds
	Emergency response workforce	Emergency services labour force
	Emergency response capability	Expenditure per capita on fire and emergency services
		Fire and emergency service volunteers
	Remoteness	Remoteness category
		Distance to medical facility
		Distance to nearest major highway
Community capital	Household support	Adults able to get support in times of crisis from persons outside the household
		Adults who provide support to relatives living outside the household
		Adults whose household could raise $2000 within a week
	Access to services	Adults who had difficulty accessing services
	Wellbeing	Adults with self-assessed health status of fair/poor
	Unemployment	Jobless families with children under 15
	Volunteering	Participation in voluntary work for an organization or group
	Place attachment	Residence in area longer than 5 years
	Crime and safety	Crime, offences against property
		Crime, offences against the person
		Adults who feel very safe/safe walking alone in the local area after dark
Information and engagement	Community engagement and hazard education	Emergency service agency expenditure on community engagement
		Emergency service agency community engagement strategy
	Telecommunications	Mobile phone coverage
		Broadband access
Adaptive capacity		
Governance, policy and leadership	Institutional character	Capacity for institutional learning
		Leadership style
		Resource levels
		Capacity for institutional innovation
	Policy and legislation	Age of legislation and/or policy
		Uptake of resilience strategic directions
	Research and development	Expenditure on research and development
		Presence of research organizations
Social and community engagement	Skills for learning	Participation in continuing adult education
		Population with university-level education
	Social engagement	Change in net migration rate

Table 3 (*continued*)

Theme[a]	Indicator dimension	Variables[b]
		Life satisfaction Generalized trust Having a say and local governance Equity and inclusion Informal social connectedness Community involvement Sense of belonging Community economic wellbeing Community leadership and collaboration

Notes:

[a] A sub-index is calculated and reported for each theme. Correlated variables will be removed in the computation of the aggregated index of disaster resilience.

[b] All data are derived from publically available secondary sources including the Australian Census, the Australian Social Health Atlas, the Regional Wellbeing Survey, the National Exposure Information System, Regional Australia Institute [In]Sight, AURIN, State and Territory agency data and evaluation of legislation/policy content.

Coping capacity consists of eight themes that express the availability of resources and abilities to prepare for, absorb and recover from a natural hazard event: social character, economic capital, infrastructure and planning, emergency services, community capital and information and engagement (Table 2). Adaptive capacity consists of two themes that express the processes that enable adjustment through learning, adaptation and transformation: governance, policy and leadership and social and community engagement (Table 2).

4.5. Indicator selection

Indicators are the variables used to determine the status of a theme. Scores of indicators have been used to assess disaster vulnerability or resilience in top-down assessments (see reviews by [10,23]). Most of these published indicators are aligned with the coping capacity part of the ANDRI conceptual model. However, much attention has been paid to the assessment of adaptive capacity in the climate change literature [33,43] and these indicators will be adopted in the Australian Natural Disaster Resilience Index. The indicators collected under each theme are outlined in Table 3. Four of the criteria of indicator selection (Table 1) were prominent in guiding the selection of indicators for the ANDRI. First, the availability of data covering the whole of Australia (Criteria 3 and 6) was essential in this top-down national-scale assessment. National-scale data coverage includes data derived from the Australian Census (or its derivatives), but also that compiled from State or Local Government level data with compatible data in each jurisdiction (e.g. crime rate, local council disaster management plans, emergency service agency community engagement activity). Second, the relationship between the indicator and natural hazard resilience (Criteria 1) was considered using available literature, particularly that pertaining to Australian circumstances and that which establishes a relationship between disaster resilience and the variable. Third, the measurability and interpretability of the indicator (Criteria 4) was applied to ensure that indicators was measurable and could subsequently be interpreted by non-experts. Approaches to indicator quantification include direct numerical measures (e.g. percentages of population, expenditure per capita) and derivation of quantitative indicators through evaluation of policy documents.

5. Conclusion

Natural hazards are expected to increase in frequency and magnitude, bringing increased risk of loss [43]. The assessment of disaster resilience sits between the theoretical domain of resilience as a way of understanding changing and uncertain environments, and the practical domain of resilience as a decision support tool for managing how societies live within changing and uncertain environments. The practice of disaster resilience assessment is entering what will be a multi-decadal phase of diverse and reflective advancement. Assessment of disaster resilience summarizes the status of resilience within a community. However, resilience assessment is only one part of a wider field of disaster resilience and further research is needed in many areas, including the empirical relationships between the potential resilience of a community derived from indexes and actual resilience measured following a natural hazard event (e.g. [63]). Given the complexity of social interactions with natural hazards [80], policymakers, emergency management agencies, researchers and the public will need to work together as a community of practice in many aspects of operationalizing ideas of disaster resilience, including in the area of assessing disaster resilience.

Reporting the design of an assessment should be standard practice in disaster resilience assessments [14,69]. This paper has reported a framework for the top-down assessment of disaster resilience in relation to the common properties of resilience assessments. The design of the ANDRI is based on coping and adaptive capacities. While the capacities idea underpins many top-down resilience assessments (e.g. [28]) the focus has generally been on themes of coping rather than adaptive capacity. The ANDRI will advance the field of disaster resilience assessment by incorporating adaptive capacities related to learning, adaptation and transformation. As assessments of disaster resilience continue to develop worldwide, reporting of their design as standard practice will track knowledge generation in the field and enhance the relationship between applied disaster resilience assessment and foundational principles of disaster resilience.

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