The Data Challenges of Monitoring Resilience

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ABSTRACT

There is a growing global demand for rigorous monitoring and evaluation of resilience and the efficacy of resilience interventions. Yet, people striving to assess resilience face significant hurdles relating to data accessibility, comprehensiveness, and quality. This paper reflects on two projects that are attempting to navigate these hurdles, as part of the 'Resilience Trajectories' programme of the Resilience to Nature's Challenges National Science Challenge. The first project, the New Zealand Resilience Index development, is used to illustrate the data-related challenges and limitations of quantitative resilience assessments. We argue that composite indicators are useful aids for beginning a robust discussion about resilience assessment, but high-level indicators must be supplemented with local knowledge and contextual information to facilitate meaningful decision making. The second project, the Data Integration and Visualisation En Masse (DIVE) web-based data catalogue, presents a partial solution to some of the resilience data challenges we have observed in the creation of the national index.

Keywords

Resilience, monitoring, assessment, data quality, metadata

INTRODUCTION

The Sendai Framework for Disaster Risk Reduction (DRR) 2015-2030 is constructed around the premise that human actions have a critical part to play in both our exposure to risk from disasters and the reduction of that risk (UNISDR, 2018). The ultimate goal of this international strategy is to reduce disaster caused mortality, ill health and wellbeing effects, and economic losses. The pathways to improvement draw on all parts of society and require significant input of resources, time, and effort. This includes understanding and building on a community's resilience. Resilience, for the purposes of this discussion, refers to a system's ability to "absorb the effects of a disruptive event, minimise adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events," (Stevenson et al., 2015, p.7).

In a finite resource environment, governments, businesses, and households need to prioritise their resources to optimise their ability to enhance disaster resilience. These decisions are incredibly complex and messy and, as a result, there is an insistent call for rigorous monitoring and evaluation of both resilience and assessments of the efficacy of resilience interventions (Bènè et al., 2017). Access to quality, reliable data is essential to support resource allocation, prioritisation, and other resilience policy decisions (Cutter et al., 2013). Unfortunately, even in the data saturated world in which we now live, quality, reliable data is not always available in a useful form and collecting primary data for the purposes of resilience assessment tends to be cost prohibitive.

Measuring Resilience

Resilience is a social construct that describes a system's capacity in relation to a disruption (another social construct). Therefore, resilience can only be "measured" by observing the properties that might influence resilience (Martin-Breen and Andries, 2011). Characterising resilience by assessing its components and determinants means gathering data points across the system of interest (Prior and Hagmann, 2014).

There are four major approaches to resilience assessment: scorecards (e.g., UNISDR city disaster resilience scorecard, UNISDR, 2014), indices (e.g., Cutter, 2016), models (e.g., NIST, 2015; Rose and Liao, 2005), and toolkits (e.g., the Earthquakes and Megacities Initiative, Khazai et al., 2015 and the Rockefeller City Resilience Framework, TRF, 2014). Scorecards are used to assess performance against pre-defined criteria associated with resilience (Sharifi 2016). They often consist of a number of questions or assessment criteria, usually with a set of scaled answers from which to select. The result can be a single 'score' or a collection of scores within a number of target areas. Drawing heavily on primary data collection means that scorecard data is relatively current. Scorecards tend to be simple to administer and useful in areas that do not have regular or reliable data collection. With scorecards there is a trade-off between comprehensiveness, cost, and respondent burden (Stevenson et al., 2015). One of the most widely used community resilience scorecards is the UNISDR Disaster Resilience Scorecard for Cities, in various stages of implementation in over 200 cities globally (UNISDR, 2017). The first level focuses on key Sendai Framework targets and indicators and requires stakeholders to participate in a one to two-day multi-stakeholder workshop to score 47 individual indicators. The second level takes one to four months of multi-stakeholder engagement to work through resilience assessments of 117 indicator criteria (UNISDR, 2017). Such a system provides a thorough assessment but can be costly to implement and difficult to get stakeholders to engage in on a regularly overtime in order to establish a measurement of trends.

Indices are another common tool for assessing resilience. An indicator is a quantifiable variable that represents a characteristic of a system or phenomena. Indicators are combined to construct an index or composite indicator to capture the multidimensional nature of a system, while distilling it into a single metric (Tate, 2011). Unlike scorecards, indices more often draw on secondary data, and can be designed to facilitate standardised comparisons across space and time. Data often needs to be aggregated from a number of sources, with different periodicity, spatial extent, and quality. If not carefully managed, this can lead to compounding uncertainties, which can undermine the validity of the results (Barnett et al., 2008). Additionally, unlike computational models, indices have no in-built forecasting ability (Stevenson et al., 2015). Composite indicators are discussed in more depth in the following section.

Computational models will often draw on indicators of system function (e.g., infrastructure systems functionality, economic productivity) and simulate the speed, efficacy, and efficiency of the system's recovery following a hypothetical disruption. For example, Miles and Chang (2011) used a series of input-output functions to assess the various probable impacts of a hazard event. Stochastic models were used to simulate the recovery dynamics, showing a sequence of possible events where the probability of each event depends on the state attained in the previous simulation (i.e., Markov chains). Fragility curves were used to calculate the potential damage and related injury or death resulting from building or lifeline damage. In a case study based on the 1994 Northridge Earthquake ResilUS modelled several household and business-level factors. The authors found that a lack of quality empirical data meant that some elements of the model were poorly calibrated (Miles and Chang, 2011). Models such as these are computationally expensive and take a high degree of expertise to design, implement, and interpret. They can be very useful for understanding limited case studies for which rich datasets are available but become less useful when trying to apply to larger areas or for having general discussions with resilience practitioners about strategy development.

Finally, toolkits can include any of the above resilience assessment methods but also provide guidance on how to conduct assessments. Additionally, they often provide guidance on how to transition from assessment into the design and implementation of resilience enhancement interventions. They may also include advice on how to monitor and evaluate those interventions once they are implemented (Sharifi, 2016). The Communities Advancing Resilience Toolkit (CART) integrated system, for example, includes community-based surveys, key informant interviews, the collection of secondary data, community workshops, aggregation and evaluation of infrastructure and ecological maps, and other capacity and vulnerability assessments (Pfefferbaum, Pfefferbaum, and Van Horn, 2011). Again, like scorecards these systems can provide high-quality up to date assessments for a community. They are very difficult and costly to implement over a large spatial scale or over time. For thorough critical reviews of community resilience assessment tools and approaches see Sharifi (2016), Cutter (2016), Beccari (2016), and Winderl (2014).

Composite Indicators

Resilience assessments that produce a standardised output (e.g., a quantitative 'resilience score' or similar) allow observers to establish a common baseline and language to facilitate mutual learning and exchange across places, institutions, and people. A tool that is widely applied for developing basic comparable measures of complex phenomena is the composite indicator (Becker et al., 2017). Composite indicators are formed by compiling a set of indicators that capture different aspects of a multi-dimensional concept (e.g., resilience) into a single index. Composite indicators are valued for their ability to simplify the measurement of concepts that are difficult to grasp (Nardo et al., 2005). They are additionally valued for their ability to facilitate communication with the public and focus the attention or "catch the eye" of decision makers (Booysen, 2002, p. 115; Becker et al., 2017; Saltelli, 2007).

Composite indicators are relatively simple to construct. It can, however, be difficult to provide the quantity and quality of data needed for statistically meaningful and representative analyses (Saltelli, 2007). Despite the proliferation of information technologies and the massive production of big data in almost every activity of our lives, those trying to construct resilience assessment frameworks reliably face issues with data availability, consistency, reliability, quality, compatibility, and sampling coverage (OECD, 2003; Brooks and Adger, 2003; Seville and Wilson, 2006). There is also a constant negotiation between quality and practicality. An index is only as good as the data that composes it and yet, the indicators that are ultimately included in an index are usually chosen because the data is relatively easy to access and manipulate (Barnett et al., 2008; King, 2001; Niemeijer, 2002).

Barnett et al. (2008) argue that using composite indicators to model complex and uncertain social-ecological resilience for large-scale systems (like countries) means that indicators are aggregated to a point where they are only able to provide a diluted understanding of the construct. That is, the quality of the data that the index is inevitably based on due to data constraints results in top-down measures of assessment only being able to present a generic view of resilience. As a result, composite indicators have limited applicability as decision making tools (Barnett et al., 2008).

In addition, Sharifi (2016) notes that although many resilience tools deem community participation and consideration to be vital, only 36% of his reviewed measures of resilience used stakeholder participation in their construction. This lack of community data, and the focus on top-down resilience measures using secondary, quantitative data, may result in a disconnect between the measure and the values of the community being measured (Gaillard and Mercer, 2013; Sharifi, 2016). Place-based assessments that incorporate local data and nuance from those who live and work in these communities are better able to produce more detailed, meaningful, and relevant insights to policy and decision makers (Barnett et al., 2008). Olazabal and Pascual (2016) also stress this point and argue that better understanding the local context and perceptions of the community can be garnered by extracting expert knowledge, which can then be used to usefully inform resilience initiatives. Making sure to include a range of representation and expertise from diverse social groups and backgrounds is critical for gaining a holistic understanding of a place-based community. Subjective measures of resilience add value to top-down measures of resilience, as people living in their own communities are better placed to understand their own capabilities and capacity to deal with disruption and change (Jones and Tanner, 2015).

This is not to say that large-scale composite indicators are useless. Quite the contrary; they are excellent tools for distilling and communicating a complex concept like resilience and starting a consistent and meaningful conversation that informs action. They are useful tools for tracking trends over time and, when constructed carefully using indicators that are empirically linked to resilience outcomes, can give communities insights into their areas of strength and areas where they need to invest more energy.

Resilience Measurement in New Zealand

To be used for decision making and interpreted at smaller scales, however, composite indicators should be supplemented with local knowledge and contextual analysis. So, while we must accept that no resilience assessment will portray a complete and accurate picture of a community's ability to absorb, respond to, recover from, and adapt in the face of hazards, we must also attempt to facilitate a consistent and meaningful conversation across multiple scales. This means having some form of common resilience baseline, while also accommodating the local knowledge and nuance that make resilience resourcing decisions palatable and practical. The latter part of this will be enhanced by better data sharing and flexible processes for aggregating our collective knowledge and piecing together a fragmented, but rich, picture of resilience that is emerging from research and practice across New Zealand.

The Sendai Framework for DRR, New Zealand's Draft National Disaster Resilience Strategy, and the Director's Guidelines for Civil Defence and Emergency Management Group Plans all refer to a need to systematically monitor progress toward both risk reduction and resilience enhancement (UNISDR, 2015; MCDEM, 2017; MCDEM, 2018). Each of these guidance frameworks also recommends finding ways toward alignment across scales. For example, the Director's Guidelines for CDEM Group Plans notes, "Group planning draws together the *National CDEM Strategy* and supporting doctrine and gives effect to these in a local context. Monitoring and evaluation underpins delivery, ensuring that activities are informed by gap analysis, and that CDEM delivery is monitored for quality," (MCDEM, 2018 p.4). While, the monitoring and evaluation directives in this document need to be designed to meet the needs of the CDEM sector and groups, they can be supplemented by clearly integrating with the National and International strategies with a common resilience assessment baseline applied consistently across the country.

Paper Structure

This paper reflects on two ongoing projects that are part of the 'Resilience Trajectories' programme of the Resilience to Nature's Challenges National Science Challenge in New Zealand. The first project, the creation of a New Zealand Resilience Index, is used to illustrate the challenges of finding data for resilience monitoring. The second project, the Data Integration and Visualization En Masse (DIVE) web-based data catalogue, presents a partial solution to some of the resilience data challenges we have observed.

The New Zealand Resilience Index

The purpose of the New Zealand Resilience Index (NZRI) is to assess the resilience of New Zealand's place-based communities over time. There are several resilience assessment approaches that have been applied in New Zealand, all of which have their merits (Kwok et al., 2018; Paton and Johnson, 2017; Pearson et al., 2013; TRF, 2014; UNISDR, 2014). The proposed NZRI is not intended to supplant these other assessment programmes; it is designed to provide a simple measurement baseline across the country. To facilitate consistent comparisons between places and across time, the baseline indicators for the NZRI needed to be quantitative (or quantised qualitative data), consistently available at a standard geographic area, and collected at fairly regular time intervals. To make the index manageable and cost effective in the long-term, we rely exclusively on cost free secondary data that is published publicly. Repeatability allows researchers, decision makers, and communities to track progress, assess the efficacy of interventions, and to evaluate the validity of the indicators post-event.

In this iteration of the NZRI we are focusing our data gathering and analysis at the Census Area Unit (CAU), which are used to define small geographic areas. CAUs are non-administrative geographic areas[1], which, in urban areas, generally coincide with suburbs and have a population of 3,000 to 5,000 people. The geographic size of CAUs in rural areas is much larger with a generally lower population. CAUs were selected the preferred 'place' as they are a standard area for data collection and are likely to capture a community of people and organisations at a local level. At this scale, we can clearly represent the intersections and interactions of human society with hazards in the natural environment. These areas are also small enough to identify the many differences between places and groups of people that shape the community's resilience to disruptions and could be addressed by community-based interventions.

There are myriad approaches to disaster resilience assessment, however, there is growing agreement about the properties that should be considered in the design of resilience assessment indices (Parsons et al., 2016; Tate, 2012). Parsons et al. (2016) lay out these common elements from the focused definition of purpose, the selection of top-down versus bottom-up assessment, defining the assessment scale, establishing the conceptual framework and structural design, and indicator selection.

For the NZRI we employed the "Kickstart 2 Measurement" (K2M) tool developed by Ivory and Stevenson (2017) to establish the structural basis for our resilience index. The K2M is a conceptual framework designed to

[1] Administrative areas are legally defined jurisdictional boundaries where areas are grouped by legal or administrative constituencies. In New Zealand, administrative boundaries, "represent voting districts, redistributions, zoning, socio-economic analysis, regional planning, service distribution and local and state government boundaries," (LINZ, 2015).

facilitate structured conversations and problem solving when considering resilience measurement. Such heuristic techniques are applied in situations where finding a truly optimal solution is impossible or impractical, but where a logical defensible satisfactory solution is desired. Currently, the conceptual framework is applied through a facilitated workshop, where users are progressed through a series of questions and measurement decisions to identify the underlying theory, assumptions, information requirements, and limitations of their resilience assessments (Ivory and Stevenson, 2017).

There are six key areas that are systematically interrogated as part of the K2M workshop process: purpose, focus, scale, disruption type, phase, and data needs and requirements (see Table 1). The K2M is composed of a series of key questions about resilience measurement designed to clarify the assumptions, barriers, and opportunities of different types of measurement. As people answer the questions their answers are refined, and the process can be iterated in a workshop or by individual users until a desired level of clarity is achieved linking resilience theory to resilience measures. The K2M starts with a specification of the purpose, focus, and scale of the desired analysis. There are then scope refinement questions specifically relevant to research involving system disruptions (i.e., the disruption type and temporal phases relative to the disruption that are of interest to the researcher), followed by a series of questions about the data required or desired for the measure (Ivory and Stevenson, 2017). Such questions include: What would you like to measure? What are you happy to [or what can you] measure? What are you struggling to measure?

Table 1. Results of the Kickstart 2 Measurement structured enquiry into the NZRI

Purpose	To assess and compare the resilience of place-based communities in New Zealand over time. To help decision makers and their communities identify collective strengths and weaknesses, and guide prioritisation of resilience building activities prior to disruptions. The NZRI will provide a consistent and comparable baseline that encourages communication and learning between different places in New Zealand. It is therefore not a definitive measure of place-based resilience, rather a monitoring tool and starting point for discussion where additional perspectives and knowledge can be added.
Focus	Place-based communities in New Zealand assessed through the lens of six community capital categories: social resilience, economic resilience, resilience of the built environment, resilience of the natural environment, cultural resilience, and governance of risk and resilience.
Scale	Sub-national at the community or neighbourhood level, geographically defined by Census Area Unit boundaries.
Disruption	Chronic and sudden onset environmental disruptions and disasters, some of which may be exacerbated by human actions.
Phase	Pre-disaster attributes that enhance post-disaster outcomes. The NZRI focuses on points of the system where resilience can be enhanced prior to a disaster event. Measures should indicate how resilient a community currently is, and its likely future resilience in the face of disruption.
Data	The NZRI will compare communities with each other over time. Data must facilitate repeatable comparisons for all small areas across New Zealand and data that is publicly available (i.e. does not have cost or permission barriers) is prioritised.

Implicit in these broad questions about data are numerous practical considerations that need to be discussed. These include data accessibility (i.e., cost and required permissions) and data quality (i.e., completeness, timeliness of collection, consistency, accuracy, and validity). Consideration of data needs often sharpens and constrains the parameters of the assessment framework. Table 1 summarises some of the outputs of the K2M process for the New Zealand Resilience Index (NZRI). In the authors' case, the K2M was run as a small group discussion with the core research team associated with the development of the NZRI.

The purpose outlined in Table 1 is the underlying conceptual framework for the NZRI: to assess the resilience of New Zealand's place-based communities over time, with an emphasis on forming a repeatable metric that can serve as a consistent and comparable baseline across New Zealand. Repeatability allows places to track progress, assess the efficacy of interventions, and to assess the validity of the measure post-event. Comparability (i.e., having a measure that can be consistently applied to each unit at the sub-national level) facilitates communication and learning between places. As a result, we need to identify measures that are collected regularly and consistently for all units at the sub-national level. The specification of publicly available data is intended to reduce barriers to repeated measurement by having clear points of access to the data and minimal cost.

The 'focus' element of the K2M (Table 1) notes that the NZRI is based on a six-capital framework. This framework aligns with the Ministry of Civil Defence and Emergency Management's (MCDEM) Draft National Resilience Framework for New Zealand (Figure 1). The framework illustrates six resilience 'capitals' that contribute to the resilience of a nation. These capitals are drawn from international research and best practice guidance for what contributes to individual, household, community, and national resilience. Resilience is an emergent property of these interacting elements of the system, and resilience itself is enacted and experienced differently at varying societal, economic, and institutional (governance) scales and by different individuals and groups across them.

Figure 1. National Resilience Framework (Source: MCDEM, 2018)

These six capitals are not independent of one another and flows of information and outcomes across capitals are essential to achieve resilience outcomes in a highly connected system. For example, governance of leadership, policy, and strategy drive decisions and investment that directly influence elements of all five other capital domains. In turn, changes to other elements of the system, such as the economy, will have flow on effects for social and socio-economic outcomes, urban growth, and resource use (among other things).

Indicator selection is based on theory, empirical analysis, or pragmatism (Booysen, 2002). It is also often informed by political or policy considerations (Booysen, 2002). For the NZRI, individual indicators have been developed following an extensive review of international approaches to measuring, monitoring, and evaluating resilience. This review led to the development of an 'indicator bank' containing approximately 1,000 indicators of resilience. The indices included in the indicator bank have a wide range of functions and approaches to measuring resilience and covered a range of geographic scales from single community scorecards to broad national level indicators.

Content analysis of the indicator bank was performed using a simple thematic coding methodology, where some thematic concepts were anticipated in the dataset (e.g., social capital) and others emerged from the coding process (Ayres, 2008). This conceptual data reduction methodology allows us to highlight a range of common resilience concepts while recognising that there were many individual metrics that could be used to assess these concepts. These concepts were used to guide the selection of individual indicators for the NZRI. We ultimately drew our resilience indicator concepts from this theoretical and empirical literature-based indicator bank. Table 2 shows a modified K2M process that has been developed for the selection of NZRI indicators to maintain consistency in decision making as the index grows.

Table 2. Modified K2M assessment process for selection of indicators in the NZRI

Focus and phase	The indicator measures resilience in terms of 'means' rather than 'ends' and so can be measured prior to a disruptive event.
Scale	The indicator is relevant to the scale of assessment (e.g. CAU) and remains valid across scales (e.g. local to national).
Relevance	The relationship between the indicator and natural hazard resilience has been verified in the academic/professional literature.
Purpose	The indicator can track change and variability in natural hazard resilience and can compare the level of resilience across space and time.
Data	The indicator measures resilience in a quantitative way, and is clear and simple in its content, purpose, and focus. Data is readily available at the required spatial scale and for the period of interest, data should be openly available from secondary sources. Data is consistent at the sub-national level, and measurement is reliable and representative of reality.

Although not part of our initial selection process, we found that the outcomes of indicators selected using the K2M align with the criteria for indicator selection outlined by Parsons et al. (2016), including: "1. The indicator reflects a justifiable element of natural hazards resilience. 2. The indicator can track change and variability in natural hazard resilience. 3. The indicator is relevant to the scales of assessment. 4. The indicator is measurable and readily interpretable. 5. The measurement method for the indicator is robust. 6. The indicator is achievable" (Parsons et al., 2016, p.5). Items 4 - 6 are captured in the data element of the K2M.

In practice, selecting indicators that meet all five criteria of the K2M or the six elements laid out in Parsons et al. (2016) is difficult. Many resilience concepts cannot yet be measured consistently at a sub-national level. The key challenge facing development and population of a sub-national index is data availability, as the information required to measure resilience for some capitals is not conveniently managed and shared in an open data environment. Indicators relating to the resilience of the built and natural environments, and for governance of risk and resilience, are particularly fragmented. In general, information is not captured for many indicators, so a large amount of effort is required to meet the NZRI's data needs.

This is not a unique challenge; multi-capital resilience indices consistently suffer from a significant gap between what measures are needed to reflect a holistic view of resilience and what can be currently measured using publicly available data. It is possible to request data from organisations and piece together novel datasets, but such an ad hoc approach is not sustainable for long-term monitoring and reporting of resilience indicators at the national and sub-national level.

Through the thematic content analysis of the 'indicator bank' containing over 1,000 potential indicators of resilience, we categorised these into approximately 60 distinct indicator concepts of place-based community resilience. Of these we have prioritised 15 indicators across the six resilience capitals, for which we have currently populated 12 and are waiting for data to be supplied by government agencies for three final indicators. It is important to note that household economic capacity requires more than one measure in its calculation. This is a function of both the complexity of the concept, but also the relatively high availability of high-quality data. Data availability allows us to add more nuance to our understanding of economic resilience compared to other concepts like cultural resilience, which has a dearth of high-quality data.

After reflecting on the indicator categories and consulting with stakeholders who will be applying the resilience indicators (regional Civil Defence Groups), we have split the institutional (governance) category into two indicators that capture institutional capacity to reduce and manage risk and three indicators that relate to DRR engagement and capacity more closely related to Civil Defence and Emergency Management (CDEM) actions.

The selection process for the 15 indicators was undertaken with two primary considerations: first, which of the roughly 60 resilience concepts are we confident of accessing high-quality spatial data for, and second, ensuring that we have a spread of indicators across all six resilience capitals and do not over measure a specific concept or capital. The latter is important, as during the development of the NZRI it became apparent that social and economic data is readily available in New Zealand via the national Census and it would be easy to populate

many indicators of this nature. Doing so creates the risk of the composite indicator being a measure of socio-economic deprivation or demographic trends rather than a measure of resilience. The 15 indicators selected for the baseline NZRI are shown as they relate to the community capital model in Table 3.

Table 3: Indicators in the New Zealand Resilience Index (metrics with an * are datasets not yet attained)

Capital Domain	Indicator	Metric(s)
Social	Socio-cultural engagement	% resident population who have engaged in voluntary work
	Long term residency	% of residents who have lived in current area for 5+ years
	Hospitalization rates	Total hospital discharged by DHB per 1,000 population
Economic	Sector diversity	Number of ANZIC codes represented in area
	Non-primary sector employment	% working age resident population not employed in the primary sector
	Household economic capacity	% working age population in fulltime employment
		% working age population with post high school education
		% population living in an equivalized household with income above income threshold*
Built	Infrastructure independency systemic resilience	Infrastructure independency systemic resilience metric
	Commercial building quality	% commercial buildings that meet at least 34% of new building standard
Natural	Land use change	% change in natural land use between 1990 and 2012
Cultural	Historic site protection	% registered historic sites damaged/destroyed since 2000
Institutional/ Governance	Land use planning for hazards	% completeness of hazard planning from district plans
	Hospital beds per capita	Number of hospital beds per 1,000 people
DRR Engagement and Capacity	Emergency support center accessibility	Average distance to designated Community Emergency Response Centre*
	Emergency support center capability	Number of emergency shelters per 1,000 people*
	Access to emergency water	% of households with emergency water for three days

Many of the roughly 60 resilience concepts in our 'want to have' list of indicators, are not currently measurable due to a lack of data, or data that has been collected for a specific purpose, which makes it difficult to align with the needs of the NZRI. One example of this is quantifying the capacity of emergency shelters in local areas, and the availability of trained staff and volunteers with emergency response skills. While we have stated a preference for data that is readily available at the national level, sheltering and welfare centre data is managed by local Civil Defence organisations, and no central data repositories of emergency shelter locations exist. As a result, this requires a data request to other regional or local agencies. For the first iteration of the NZRI we have opted to aggregate this information ourselves from the various regional and local groups, with the aim of developing a clearer process in the future of quickly updating this information for tracking. An indicator that we could not aggregate, though it is identified as important, is the number of trained and skilled people who can respond during an emergency event in a given area. Disaster response training is a niche field, for example, Urban Search and Rescue teams, but many people who are first aid qualified work in health and safety focused roles, such as sport and recreation staff (e.g. lifeguards), or work in healthcare, police, and firefighting roles (both fulltime and volunteer). These people are reasonably trained and skilled to aid in an emergency. However, they may not be included in measures of trained emergency response personnel. Developing a comprehensive measure for community response capacity will require the combination of many datasets, which are not currently available at the national level. When considering who in the community is well placed to respond and help others in an emergency situation, we need to consider a wide range of skillsets and organisations, and data about these people is very fragmented. As a result, a large amount of time can be spent seeking out, accessing, combining, and transforming data to meet the needs of a single indicator to include in the NZRI.

Similarly, we have included two datasets compiled by researchers into the NZRI. These datasets have high quality national coverage, but are not publicly available and may not be consistently repeated going forward. The first dataset is based on an assessment of hazard planning quality based on information aggregated by researchers based at GNS Science (Saunders et al., 2015). Their database provided a comprehensive national review of regional and district plans conducted in 2013 and 2015. This systematic review quantitatively coded the elements of each plan that met high-quality hazard and coastal management standards. This has allowed us to derive a planning quality "score" for every territorial authority in New Zealand. The second dataset is based on the work of Pant et al. (2018) and provides an assessment of infrastructure resilience as a function of interdependent critical infrastructure network vulnerabilities. Both of these datasets provide useful, high-quality data for the NZRI but, if they are not updated regularly, they will need to be dropped or replaced with an alternate dataset, making trend analysis more difficult.

THE DIVE PLATFORM

In New Zealand, as is the case elsewhere, full understanding of resilience should incorporate multiple sources of high-quality data. This moves beyond traditional forms of data such as census data, and may include local and research data, individual and group narratives, and other resources that may not be published, or even available to those researching this complex construct. Despite the country's mandate that data and information should be open, readily available, and well managed (Internal Affairs Te Tari Taiwhenua, 2011), good metadata standards and data sharing processes are still lacking in New Zealand. In order to enable an ongoing, "live" contextual understanding of community resilience, platforms capable of facilitating data sharing and collaboration, and vastly improving understanding of good metadata standards, are needed. New Zealand's commitment to the Sendai Framework for Disaster Risk Reduction also requires "real time access to reliable data, the use of space and in situ information, including geographic information systems (GIS), and use information and communications technology innovations to enhance measurement tools and the collection, analysis and dissemination of data" (UNISDR, 2015).

There is currently no unified place where researchers and stakeholders can share and find hazard related information (Stevenson et al., 2018). The Data Integration and Visualisation En Masse (DIVE) Platform, a project funded by the Resilience to Nature's Challenges National Science Challenge and QuakeCoRE, is an attempt at creating a unified space for DRR and resilience data that is curated, archived, and searchable. Furthermore, DIVE provides data literacy resources to facilitate learning around metadata.

The DIVE research team facilitated a consultation process using workshops, interviews, and surveys to explore the concepts of better data management systems. More specifically, the research team was interested what a data manage practices could enhance the resilience of research programmes and, ultimately, communities in New Zealand. This resulted in several key outcomes about the critical data needs of researchers (Stevenson et al., 2016). Some of these included:

- Systems for knowing about ongoing research prior to publication
- Enhanced data searchability across institutions
- Developing systems to facilitate safe, easy, and desirable data sharing
- Establishing standards and guidelines for transdisciplinary management of data

A beta prototype of DIVE was created following these workshops to provide a web-based interface for data and metadata entry and cataloguing. With the goal of developing consistent metadata entry and data sharing processes, educational content surrounding good metadata and geospatial data practices were created to increase uptake of the DIVE platform.

CKAN, an open source data platform, was used to create the DIVE interface. Users can register for an account, upload metadata (with an optional ability to upload data), and search for specific concepts using keywords. DIVE is also able to categorise both users and data to enable better collaboration and enhance searchability. The focus of the creation of DIVE was to deliver a minimum viable product allowing users to share resilience and DRR related metadata. Another focus was to allow for the sharing of unique datasets. For example, a dataset of Anglican heritage churches in New Zealand will be entered into DIVE. This dataset includes information including the location, year built, construction type, proneness to earthquake damage, notes about vulnerabilities and other useful and vital data. Datasets such as these are often unavailable publicly but have the potential to enable innovative research and enhance DRR and resilience understanding.

DIVE users are able to share information about past and current research endeavours even if they choose not to share complete datasets due to privacy or copyright issues. This is achieved by uploading metadata, or data about data, onto the platform. DIVE contains a comprehensive data entry form, which allows users to enter high quality metadata and improves the ability of others to interpret and build on resilience research. The 'organisations' feature allows a user to see and search all of the datasets from a particular organisation in one place. It additionally allows members of that organisation to categorise their data by entering their respective organisation during the data entry process. Users can also create their own groups and add datasets that are already in DIVE into one easy-to-find folder. This feature has the potential to facilitate collaboration through the cataloguing of datasets for a project, team, or theme. Stevenson et al. (2018) discuss the full development process for DIVE in detail.

DISCUSSION

Building the resilience of New Zealand's people, places, and economy to ensure safety, stability, and prosperity in the face of natural and man-made hazards is a national, and now international, imperative following New Zealand's commitment to the Sendai Framework. Understanding the country's current state of resilience and achieving improvements requires transdisciplinary and cross-institutional collaboration and research. However, such a model currently challenges the status quo around sharing and managing data (Medyckyj-Scott et al., 2016). Data gaps and inefficiencies often hinder the progress of disaster risk reduction (DRR) and resilience researchers, and effective information management is needed to ensure that meaningful progress can be made. This involves creating spaces to allow data to be captured, safely shared, and managed to ensure quality, appropriate use, and ongoing development.

In 2011, the New Zealand government approved a set of principles, asserting that the data and information it holds should be open, readily available, well managed, reasonably priced, and re-usable unless there is a reasonable expectation of information protection (Internal Affairs Te Tari Taiwhenua, 2011). This is underscored by the Open Government Data Programme which champions an 'open by default' cross-government data ecosystem. Policy recommendations from the Ministry of Business, Innovation, and Employment (MBIE) extend this ethos to publicly-funded science data, with the intention of managing and sharing information for better collaboration, more efficient and powerful science, and greater connectedness to end-users (Ministry of Research Science and Technology, 2010).

The DIVE platform builds on these recommendations and responds to a practical need expressed by people working in the field of DRR and resilience in New Zealand. Having more people and organisations share their work and observations of resilience, will help create a community of localised, nuanced information that can complement and elaborate on the baseline NZRI. Ongoing work through the Warrant of Fitness, another project within the 'Resilience Trajectories' programme, is developing a framework to pair the top-down NZRI with localised, bottom-up data to enable communities to better understand their resilience strengths and weaknesses, and to monitor resilience over time.

CONCLUSIONS

Going forward we will continue an iterative process of consultation and development as both the NZRI and the DIVE Platform are 'road tested' by stakeholders across research and practice. At all stages we will need to ensure that care is taken with how resilience assessments and interventions are applied, recognising the possibilities and limitations of our data rich environment. There is an ongoing need to build relationships between organisations that collect and process data like Land Information New Zealand (LINZ), MBIE, and StatsNZ, and data users. Through mutual engagement the data collected can be shaped to better suit the needs of end users, more clearly linking what we want to know with what we want to do. Additionally, supporting data sharing initiatives like DIVE will facilitate the creation of a community of practice among researchers and research stakeholders as we strive to build a more comprehensive understanding of resilience and operationalise those understandings into measurable resilience outcomes for New Zealand.

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