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Current and potential applications of typologies in vulnerability assessments and adaptation science

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Helping Australia Adapt to a Changing Climate

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Contents

List of Figures

List of Tables

ABSTRACT

Typologies are a systematic grouping of entities or units of interest based on similarity. Typologies are widely applied in a variety of domains of research and practice including natural resource management, agriculture, health, marketing and development. They are used mainly to reduce complexity in the domain of concern to improve understanding and communication, detect patterns, aid decisions, prioritise and allocate resources, and tailor a variety of activities, strategies and processes. In this paper, we assess the current use of typologies within the realm of climate vulnerability assessments and adaptation sciences to better understand the potential use of typologies to further our ability to prepare for climate change risk. We found a limited number of climate vulnerability and adaptation studies that directly and indirectly developed typologies to help understand climate risk, and the example applications of typologies that have been developed have limitations in rigour, validity and even practical utility at times. There is especially a gap in the coverage of a typology work for the purpose of vulnerability assessments. The first gap is the potential application of typologies developed in the fields of cultural studies, learning and social psychology into the studies of behavioural aspects of vulnerability and adaptation to climate change. The second is the development of participatory typology as a communication and social learning tool that improves understanding of vulnerabilities to climate change and enhances collaborative adaptation. These limitations and gaps provide opportunity for potential improvement and expansion of typologies application in the research of vulnerability and adaptation to climate change.

1. INTRODUCTION

"There are three creative ideas which, each in its turn, have been central to science. They are the idea of order, the idea of causes, and the idea of chance." Bronowski (1951 p.12)

Ordering or putting things together into groups based on their likeness, while they are not identical, is a ubiquitous human conceptual undertaking that helps make sense of every day life. For science, , classification is a fundamental exercise (Bronowski 1951; Bailey 1994) and a typology is one example of a classification system. Literally, typologies refer to the study of types or categories. It is an ordering or a systematic classification of units of interest based on the similarity/dissimilarity of their states, characteristics, properties or behaviours (Buddeimer et al. 2008, Bailey 1994). A typology refers both to the process of classification and to the output types or categories from the classification process. In the literature, units considered for a typology are diverse and include genes, concepts, language, methodologies, processes, places, individuals, communities, regions, landscapes, or countries. Outputs of a typology can be types, classes, levels, or ranks grouped into categories.

The meaning of a typology and taxonomy are blurred and are often used interchangeably although some identify them as two approaches to ordering or classification (Lambert 2006, Bailey 1994). Typologies are often applied to social and human made phenomena and are developed for a specific purpose. Types and categories are mainly deduced conceptually and qualitatively, and few characteristics of the units of interest are used in this derivation. A good typology example is the Myers-Briggs 16 possible personality types (Myers and Briggs Foundation, 2010) extrapolated from the typological theories proposed by Carl Gustav Jung (Jung 1923). In contrast taxonomy is a general classification scheme often applied to naturally occurring entities, where taxa or categories are inductively and empirically derived, and it considers many characteristics of the units classified (Bailey 1994, Lambert 2006). An example of taxonomy is the hierarchical ordering of the animal or plant kingdom.

There are different approaches to creating typologies. Bailey (1994: 30-32) recognises three: conceptual, empirical and operational. The conceptual type of typology is generally derived deductively through a theoretical exercise. Conceptual typologies often act as ideal categories without any empirical counterpart. However, they can also have significant empirical value where they are later confirmed by measurements. For example let us consider that a democratic systems can be assessed based on the level of two important dimensions: say the rights and responsibilities it confer to individuals in the system. Assume that each dimension has three levels – low, medium and high – that can then conceptually generate nine types of democracy. The practical utility of these types can be assessed by mapping nations into these democracy categories.

The empirical types are derived inductively through measurement of empirical cases and grouping them by similarity. An example to this can be market segments generated statistically using various cluster analysis of socio-economic data of potential consumers.

The operational types of typologies are results of combined deductive and inductive approaches. An example of this is a matrix of vulnerability deductively developed by Nelson and colleagues (2010b) from three levels of exposure-sensitivity on the one hand and adaptive capacity on the

other and. Then, using the statistical analysis of data across a variety of exposure –sensitivity and adaptive capacity indicator values, Nelson and colleagues inductively mapped the vulnerability of Australian broad –acre farming units. .

Traditionally, typologies have been employed in many fields of inquiry acquiring slightly different meanings. In linguistics, it means the study and classifications of languages according to their structural features (Nicholas 2007). Typologies in anthropology have been applied in studying the classification of races (Brown and Armelagos 2001). In theology it refers to the identification and interpretation of the resemblance of some Old Testament characters as allegories or types foreshadowing the New Testament (Campbell 2010).

Typologies are also extensively used in several other fields of interest: health, agriculture, natural resource management, administration, development, marketing just to mention a few. Applications include profiling landholders based on their value systems and socio-economic characteristics (Solutions 2003), on their propensity to adopt new technologies and practices (Rogers 1995), identifying types based on characteristics of farming systems (e.g. Emtage et al. 2006), grouping of countries based on the level of their human development (UNDP 2010), and regionalisation or formation of regions from local units with similar fundamental social, and economic or/and environmental characteristics to serve different purposes (e.g. Landais 1998, Australian Government 2000, Maru et al. 2006).

Typologies as an approach and output are used to achieve several broad outcomes. These include: 1) reducing complexity and providing parsimony essential for ease of understanding and communication, 2) assisting selection of representatives for a detailed study, 3) identifying dissimilarities and assisting comparisons between types or categories, 4) detecting patterns and identifying gaps, 5) tailoring a variety of activities, strategies and processes such as : education, research, policy, development approaches, programs, or marketing, and 6) prioritizing resource allocation, investment or aid.

As we shall see in the next section, the use of typologies in vulnerability and adaptation to climate related perturbations is still in its early stages requiring more refinement and work. The purpose of this paper is to explore the current uses of typologies, the strengths and weaknesses of typologies in vulnerability and adaptation research domains and to identify potential applications and improvement.

This paper has four sections. The second section that follows this introduction provides the literature search methods and findings on current applications of the typology concept in vulnerability and adaptation research and practice. Building on these findings, the third section discusses gaps and potential applications of the typology concept in vulnerability and adaptation assessment domains. Concluding remarks are given in the fourth section.

2. CURRENT TYPOLOGY APPLICATION IN VULNERABILITY AND ADAPTATION RESEARCH

2.1 Search methods and results

Assessment of the current application of the typologies concept within the vulnerability and adaptation literature was conducted using data base searches. We used the ISI Web of Knowledge[SM] to search seven databases: three citation databases, two conference proceedings citation indexes and two chemistry databases. Searches were conducted on 7 January 2011. Searches were specified by search terms on title and topic.

Two categories of search terms were used to identify articles on vulnerability and/or adaptation to climate variability and change directly or indirectly involved in typologies. The first search category was aimed at finding articles with direct and explicit use of the term "typology". The second category was a search that included terms such as indicator*, index, assess*, measur* to identify articles that might have been indirectly involved in a typology work. Each of the categories of articles found were then refined with the term climat* to find only those articles related to climate variability and change as the main domain of interest. The search terms and all results from search on title, topic and climate (climat*) as domain filter are given in Table 1.

Table 1: Summary results of direct and indirect typologies on title and/or topic with climate (climat*) as a domain filter.

Terms searched	*Number of references searched by Topic and (Title)*				*% of climat* refs produced in the last 4 years*
	all years		*2006-Jan 7th, 2011*		
	All domains	*Climat**	*All domains*	*Climat**	
Vulnerability & Typology	135 (5)	13 (1)	49 (1)	11 (1)	85
Adaptation & Typology	305 (110)	23 (1)	103 (2)	14 (0)	61
Vulnerability & Indicator* + Vulnerability & index	4431 (201)	450 (8)	1892 (76)	285 (7)	63
Adaptation & Indicator* + Adaptation & Index	15261 (347)	938 (8)	4837 (102)	411 (4)	44
Vulnerability & Assess*	12069 (1071)	1422 (95)	5129 (487)	784 (40)	55
Vulnerability & Examin*	9282 (44)	525 (1)	3292 (15)	289 (1)	55
Vulnerability & Measur*	9995 (120)	681 (6)	3665 (38)	391 (5)	57
Adaptation & Assess*	36188 (643)	2340 (82)	11687 (219)	1329 (53)	57
Adaptation & Examin*	39632 (168)	1738 (2)	11257 (29)	806 (2)	46
Adaptation & Measur*	53220 (927)	2534 (22)	14276 (170)	1127 (13)	44

Only a few direct typology articles in the search related to vulnerability and adaptation to climate variability and change were found. Figure 1 shows typology papers by vulnerability or adaptation by climat* filter as percentage of the total number of articles found for the vulnerability and adaptation sub-category searches.

Compared to articles with explicit typology work, searches on article titles for indirect typology articles returned a significant number of articles (Table 1). However, as shown in Figure 2, the number of articles in the climate variability and change domain are comparatively small. Furthermore, most of the indirect typologies are by-products of the application of indicators, indices or assessments of vulnerability and adaptation, where places or people at different scales, countries, regions, communities, and households are ranked and/or categorised based on the level of vulnerability or adaptive capacity.

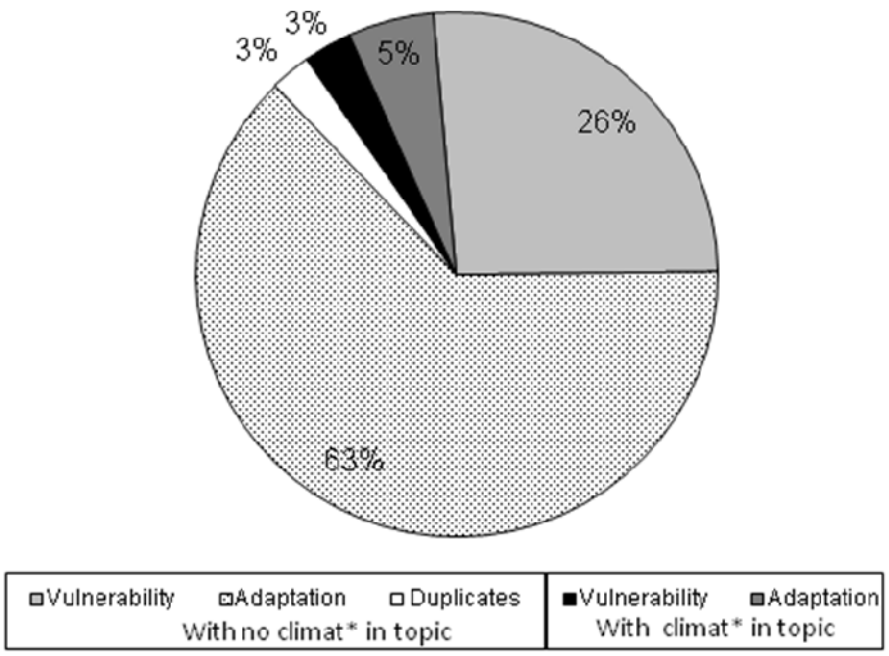

Figure 1. The proportion of references found for all years using a topic search on the term 'typology' with the additional filters 'vulnerability' and 'adaptation' and 'climat*'. Duplicates using the filter 'vulnerability' and 'adaptation' are indicated.

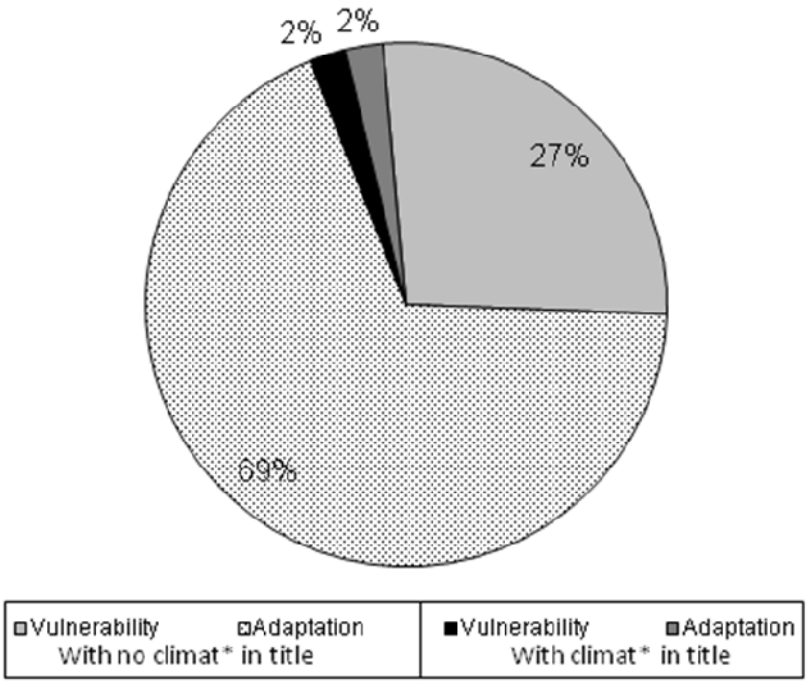

Figure 2. The proportion of references found for all years using a title search on terms that might indirectly relate to a typology. Indirect search terms are grouped into those including the term vulnerability and adaptation and that include or exclude the term 'climat*'

The data base search was not sufficient to capture all articles that contained a typology work based on the search terms that we used. To capture articles that it overlooked, we manually searched for some widely cited articles that were meta-analyses of vulnerability and adaptation assessments and found additional references mainly focusing on a typology work related to interpretation, approaches to vulnerability as well as articles that have categorised and mapped places and communities by levels of vulnerability and adaptive capacity.

After the articles were searched by the terms and filtered with climat*, or manually searched through reference trails of meta-analytic articles, their relevance as a typology paper was determined by whether the article developed typologies or categories of any unit of interest to vulnerability and adaptation. The unit of interest ranged from places and people, but also included concepts on adaptation, vulnerability, and its components of exposure, sensitivity, adaptive capacity as well as related concepts such as perturbation.

Types of relevant typology work follow the general two category distinctions made in the search terms. As shown in Table 2, direct typology work focused on different aspects of vulnerability and adaptation including typologies of vulnerability factors to hunger, typologies of vulnerability assessment approaches, forestry management plans, risk management interventions, and adaptation options. Table 2 also shows several articles involved in indirect typologies, including the ranking and grouping of places/ people as a by-product of application of vulnerability or adaptive capacity indicators and indices. Ranking and grouping places or peoples according to the nature and level of vulnerability and adaptive capacity have been used to inform policies, investment and funding decisions at international, national and local scales.

Table 2. Grouping and application of typologies used in articles found by electronic and manual searches

Unit categorised	*Objective*	*Method*	*Authors*	*Remark*
Adaptation options	Classify and characterize agricultural adaptation options which otherwise were proposed ad hoc in the literature	Review, stakeholder views	McLeman et al. 2008, Smit and Skinner 2002)	
Climate extremes	Describe influence of extreme events on vulnerability of sectors and regions	Conceptual exercise	Jones and Boer 2001, Schneider and Sarukhan 2001)	
Factors of vulnerability to hunger	Comprehensive consideration of factors of vulnerability to hunger in the context of climate change. Applied for country comparisons and prioritisation for aid	Review	Downing 1991	
Climate risk management interventions	Three distinct stable states proposed in poverty trap dynamics	Review	Hansen et al. 2007	
Population by vulnerability	Explore the influences of population and demographic changes on adaptive capacity and vulnerability to climate change	Review, conceptual exercise & empirical finding	McLeman 2010	
Forestry management plans	Determine to what extent they address climate change	Conceptual identification of dimensions	Ogden and Innes 2008	
Method & tools	Overview of methods and tools suited to assess vulnerability of forests, forest ecosystem services and forest-dependent people sectors to climate change	Review	Locatelli et al. 2008	
Vulnerability meaning & interpretation	Reduce confusion on multiple interpretations of the concept	Review & expertise in vulnerability science	Brook 2003, Kelly and Adger 2000, O'Brien et al. 2007	
Vulnerability assessment approaches	Inform work on integrative assessment approaches	Reviews	Adger 2006, Cutter 1996, Eakin and Luers 2006, Fussel 2007, Fussel and Klein 2006, Preston 2010, Turner et al. 2003	
Place/people vulnerability	Understand comparative vulnerability of people and places Inform policies Prioritise countries for adaptation funding	Several Indicator based indirect typologies	Balasubramanian et al. 2007, Cutter et al. 2003, Diffenbaugh et al. 2007;, Sullivan and Meigh 2005, Yohe et al. 2006	Data driven clustering
			Adger et al. 2004, Brooks et al. 2005, Crimp et al. 2010, Gbetibouo et al. 2010, Hahn et al. 2009, Nelson et al. 2010, O'Brien et al. 2004, Perch-Nielsen 2010	Theory informed
			Adger and Vincent 2005, Haddad 2005, Nelson et al. 2007, Vincent 200	Theory informed adaptive capacity ranking & grouping

2.2 Utility of current typologies

From the range of typology work found through our search, we select a few examples and discuss the details of their objectives and application to illustrate their utility. The typology work selected in this discussion have been adopted and applied as a classification tool in other studies.

2.2.1 A typology of adaptation options

Smit and Skinner (2002) developed typologies of farm-level adaptation options from Canadian farming system adaptation experiences. Adaptation options were grouped into four main categories (typologies) that were not meant to be mutually exclusive; rather, the typologies were based on the scale at which the adaptations were undertaken and the stakeholders were involved. The adaptation option typologies were (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. The first two typologies were principally the responsibility of public agencies or agri-business and part of a more system-scale or macro scale level of adaptation. The third and fourth categories involved farm-level decision-making by producers. All four categories could be applied and integrated into an adaptation plan, and certain types of adaptation affected the necessity or application of other adaptation options. In this case, the typologies created identified different categories of adaptation that needed to be developed in an agrarian system in order to protect farmers from the effects of climate change.

McLeman et al (2008) adopted and applied this adaptation option typology to analyse the way by which rural people of Sequoyah County, in eastern Oklahoma, USA, adapted to chronic drought and crop failure in the 1930s. They found it useful in that it assisted in identifying successes and missed opportunities by public policy makers that needed to be considered in current and future adaptation strategies.

2.2.2 Typologies addressing vulnerability interpretations

There are several articles that have developed a simple typology of vulnerability interpretations with the broad aims of reducing confusion over the meaning of vulnerability that otherwise negatively impacts it's utility. A list of authors and their typologies are given in Table 3. The articles are related to one another in that typologies developed later build and expand on previous ones. For example, O'Brien et al (2007) draw on two categories of Kelly and Adger (2000): starting point and end point, to provide more succinct but inclusive categories: contextual and outcome. O'Brien et al (2007) also note the differences between these two categories not as a mere difference in interpretation of the concept of vulnerability, but as a fundamental paradigmatic difference in framing the climate change problem. We will raise this difference and its implication on a typology of approaches later in the discussion section.

Another development that linked the typology of interpretation with that of approaches to vulnerability is work by Fussel (2007). Fussel (2007) critiqued the dichotomous nature of previous categories and suggested a more elaborate and expanded presentation of vulnerability situations. He uses a matrix of vulnerability factors deemed important in definitions of vulnerability (e.g. internal and external dimensions) as well as the biophysical and socio-economic determinants of vulnerability. He added the qualifiers that factors needed to be cross-

scale and integrated to accommodate interpretations and approaches that consider both internal/external dimensions and socio-economic/biophysical determinants respectively.

The vulnerability concept is well clarified by these different articulations of the different types of interpretations. The articles in Table 2 have been used in the latest vulnerability related reviews (e.g. Pearson et al. 2011, Preston 2010, Preston and Stafford-Smith 2009) to help explore how the diverse vulnerability conceptualisations are applied in the general and sectoral practice of assessment such as in agriculture.

Table 3.Typologies of interpretations of vulnerability

Authors	*Vulnerability interpretation categories*	*Description*
Kelly and Adger 2000	Starting-point	Define vulnerability in terms of the human dimension alone as 'the capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard'
	Focal -point	Vulnerability as an overarching concept defined in terms of the exposure to stress and crises, the capacity to cope with stress, and the consequences of stress and the related risk of slow recovery.
	End-point	Vulnerability as the adverse consequences that remain after the system in focus is exposed and adaptation processes have taken place
Brook 2003	Biophysical	In terms of the amount or potential damage caused to a systems by a particular climate related event or hazard
	Social (or inherent)	As a state that exists within a system before it encounters a hazard event
O'Brien et al 2007	Contextual	A process-based and multidimensional view of climate – society interaction that generates contextual vulnerability
	Outcome	A linear result of the projected impact of climate change on particular exposure unit (which can be either biophysical or social), offset by adaptation measures
Fussel 2007	A matrix of "internal" and "external" factors by "socio-economic" and "biophysical factors" to define a vulnerability situation	
	Internal Socio-economic Biophysical	Emphasis on internal social-economic vulnerability factors such as income, social networks and access to information Emphasise on internal biophysical vulnerability factors such as topography, land cover and environmental conditions
	External Socio-economic Biophysical	Emphasis on external social-economic vulnerability factors such as national policies aid and economic globalisation Emphasise on external biophysical vulnerability factors such as severe storms, earthquakes and sea-level change

2.2.3 Typologies that address the various approaches to vulnerability assessment

The identification of categories of approaches, methods and tools to vulnerability assessments has also been a preoccupation of many authors (for example see UNFCCC compendium 2008). The interpretation of the vulnerability concept and the approaches for its assessment are quite linked. For example those who interpret vulnerability as an inherent state or condition of the social system mainly apply political economy/ political ecology approaches to assess it. Those who interpreted it as property that emerges from a context and interaction of the biophysical and socio-economic dimensions of a place tend to employ integrated approaches. We will discuss examples of both the social and integrated approaches to vulnerability assessment using indicators-based articles in the next section.

Categories of approaches are identified based on different but related criteria. Some articles identified approaches based on the factors they focus on such as hazard-risk or dimensions they emphasise such as socio-political and economic conditions in interpreting and assessing vulnerability. Other articles emphasised lineage or evolution of the approaches as a major criteria to categorise them. We describe Eakin and Luer's (2006) work as it highlights both historical accounts and captures the dimensions emphasised in each category of approaches.

Table 4. Typologies of vulnerability assessment approaches

Author	*Types of approaches*	*Description*
Turner et al 2003	Risk hazard models	Consider the impact of a hazard as a function of exposure to the hazard event and the dose–response (sensitivity) of the entity exposed
	Pressure & release models	Define risk explicitly as a function of the perturbation, stressor, or stress and the vulnerability of the exposed unit
	Expanded vulnerability	Direct attention on coupled human-environment systems paying attention to elements such as multiple interacting stressors and the sequencing of them, exposure and hazard experience of the coupled system, sensitivity coping and adaptive capacities as well as nested scales and dynamics of hazards, coupled systems and their responses
Fussel and Klein 2006	Risk– hazard framework	Conceptualizes vulnerability as the dose – response relationship between an exogenous hazard to a system and its adverse effects – approximates concept of sensitivity in the IPCC terminology.
	Social constructivist framework	Vulnerability as an *a priori* condition of a household or a community determined by socio-economic and political factors. Focuses on the differential abilities of communities to cope with external stress.
	Integrated framework	Vulnerability as an integrated measure of the expected magnitude of adverse effects to a system caused by a given level of certain external stressors

Eakin and Luers 2006	Risk-hazard or biophysical	Consider negative outcomes as functions of both biophysical risk
	Political economy/ Political ecology	Factors and the "potential for loss" of a specific exposed population Characterized by analyses of social, economic and political processes, with interacting scales of causation and of social difference: Why are particular populations vulnerable? How are they vulnerable? Who is vulnerable?
	Ecological resilience	Focuses on coupled social-ecological systems emphasising the implications of social and environmental change across the broader geographic space, human activity is just one of the driving forces and humans are only one of the affected species.
Adger 2006	Antecedents	Vulnerability as a failure of entitlements and shortage of capabilities
	Vulnerability to famine& food insecurity, hazards	Vulnerability as likelihood and consequence of hazard
	Human ecology/ Pressure and release Successors	Structural analysis of underlying causes of vulnerability to natural hazards/ Further developed human ecology model
	Vulnerability to climate change & variability	Explains present social, physical or ecological system vulnerability to (primarily) future risks, using a wide range of methods and research traditions
	Sustainable livelihoods & vulnerability to poverty	Explains why populations become or stay poor based on analysis of economic factors and social relations
	Vulnerability of social-ecological systems	Explains the vulnerability of coupled human-environment systems.
Fussel 2007	Risk-hazard	Internal biophysical vulnerability
	Political economy	Cross-scale socioeconomic vulnerability
	Pressure-& release	Internal integrated vulnerability
	Integrated (e.g. hazard-of-place)	Cross-scale integrated vulnerability
	Resilience	Cross-scale (?) integrated vulnerability

An example of a typology of approaches

Eakin and Luers (2006) explore the various types of vulnerability assessments that arise from disparate fields of research and come up with a typology of approaches to vulnerability assessments. The conceptual lineages have been classified into three types. The Risk-Hazard approach considers the negative outcome of the risk as a rough equivalent to vulnerability such that the consequences and impacts are proxies for vulnerability. This is a highly technical way of looking at vulnerability and what constitutes vulnerability in a system. The Political Economy/Political Ecology approach to vulnerability analysis have evolved to focus on the social and economic processes of systems and cultural factors to explain differential exposure to

hazards, their impacts, and the ability to recuperate and adapt. The Ecological Resilience approach looks at vulnerability as a variety of stresses and shocks acting on and within coupled human-environment systems. Vulnerability is seen as a dynamic property of a system in which humans are constantly interacting with their environment. Eakin and Luers (2006) argue that the various approaches are in fact complementary and are all necessary to address the full complexity of vulnerability as they all address different components of understanding vulnerability in social-environmental systems. In their analysis, they encourage the development of more integrated and hybridized forms of assessing vulnerability in the hopes of increasing the analytical understanding of vulnerability. Similar classification of vulnerability research approaches have been subsequently developed by different authors (Adger 2006, Fussel 2007).

2.2.4 Indicator based vulnerability categories of places and communities

Indicator based approaches to vulnerability assessment have been used to rank and categorise peoples (households, communities) as well as places (e.g. costal lines, tourist destinations, districts, regions, countries) based on their relative level of vulnerability to climate change. Two categories of indicator based methods are identified in the literature: deductive (theory driven) or inductive (data driven). In the deductive methods, an articulated theory or framework guides the selection of methods, indicators and the sourcing of data. In inductive or data driven methods, a typology is a by-product of a statistical analyses that reduces data dimensions and clusters groups with similar levels of vulnerability or adaptive capacity.

Theory driven or deductive methods of vulnerability assessment are claimed to be superior to those data driven methods (Downing 2003, Nelson et al 2010a). The justification is that deductive methods provide a rigorous conceptual understanding of vulnerability or adaptive capacity that underpins and ensures a selection of methods and indicators that are transparent, stable and intuitively meaningful to users (Downing 2003, Nelson et al 2010a).

Indicator based assessments (inductive) are often influenced by how vulnerability is interpreted. If vulnerability is interpreted as a social condition a priori to exposure, a vulnerability index is constructed from socio-economic indicators used to rank and categorise relative vulnerability of places and people (Cutter et al 2003).. If vulnerability is considered as emergent from the interaction of environmental social and economic determinants (deductive), indicators of these dimensions are assessed and integrated to rank and categorise places and communities (Brooks 2003). What follows is a discussion of examples of indicator based typologies generated from restricted or multiple dimensions.

Typologies developed from single dimensions

Many vulnerability assessments have been developed with a particular goal in mind, leading to analyses that require single dimensions of data. Although such assessments can be very useful for the specific question at hand, there may be limitations to the general vulnerability knowledge gained from the results and to the broad applicability for decision making and action. For example, Cutter et al. (2003) used US County-level socioeconomic and demographic data to construct an index of social vulnerability to environmental hazards, called the Social Vulnerability Index (SoVI) from which typologies of vulnerability (low, medium,

high) were created based on the standard deviation of each county from the mean. Counties with SoVI scores greater than +1 standard deviation were labelled as the "most vulnerable" typology. Although they were able to create typologies, they found that counties within the same vulnerability typology were not socially vulnerable to the same factors. Manhattan Borough of New York City was considered the most socially vulnerable county based on the density of the built environment. Kalawao, Hawaii was also in the top five most vulnerable counties, but its vulnerability was derived based on the age of its residents, the race and ethnicity of the county, and personal wealth data. Although vulnerability categories could be identified, actual aspects of vulnerability were not equivalent across the typology.

The restricted dimension assessments represent a majority of the assessments at present where one specific goal and type of vulnerability is examined. However, there has been an increasing amount of criticism and scepticism over their ability to measure vulnerability coherently (Eakins and Luers 2006, Preston 2010). A greater move toward comprehensive assessments where more diverse information is integrated may allow for multi-dimensional information to be considered simultaneously.

Typologies developed from multiple dimensions

The ability to integrate data from several dimensions into one vulnerability assessment can by very powerful for understanding the full vulnerability of a unit of interest. Consideration of multiple dimensions is also essential to compare and develop typologies of units of interest based on the level of their vulnerabilities to climate change. In a multi-nation scale example, Brooks et al. (2005) present a vulnerability assessment using a range of economic, health, social, and environmental indicators aggregated at the national scale to determine the relative vulnerability of nations to climate change. Using 11 indicators of vulnerability, they constructed an index to measure the vulnerability of each nation, and typologies of vulnerability were created based on the quintiled index score of all indicators. The countries with the highest scores (11-13) were classified as the most vulnerable group, and the remainder were classified as moderately to highly vulnerable. Countries were classified based on a relative vulnerability scale, as all countries were vulnerable to climate change in some manner. They identified the Sub-Saharan countries of Africa as the most vulnerable group of countries, as many of them fell into the "most vulnerable" group with the lowest quintiled scores.

In a national scale example, Nelson et al. (2010b) created general typologies that delineated least, moderately, and most vulnerable rural areas of Australia to climate change by integrating exposure and adaptive capacity measurements in consultation with local stakeholders. By considering both the risk and adaptive capacity of the community as an integrated unit, they were able to identify strengths as well as weaknesses in the given communities. The analysis of the various types of capital (e.g. human, financial and natural) observed in a particular community helped highlight policy opportunities for increasing adaptive capacity of communities at greatest risk to climate change.

Lin and Morefield (in press) present another national scale example methodology for integrating multiple lines of data using a visual format called the 'Vulnerability Cube' in order to visualize how communities compare in vulnerability characteristics to one another. This analysis utilized socioeconomic and environmental data to assess both environmental vulnerabilities of the communities as well as the adaptive capacity inherent in the community. The goal of the

analysis was to create distinct vulnerability typologies which describe a specific vulnerability profile of the communities in the typology. Based on the typology that a community fell in, adaptation options could be developed to help ease the development of "next-step" management choices for the community. The hope is to create vulnerability typologies that allow communities to identify their specific vulnerabilities more concretely and to identify potential adaptation options that may be most useful for their particular circumstance.

Such examples show the diverse ways in which integrated assessments of vulnerability can use typologies to better understand both the vulnerability of the given unit of analysis as well as identify the adaptation potential of these communities. Although the examples given are performed at national to multi-national scales, the methodologies described can be applied at small scales (regional, state) as well depending on the goals of analysis.

3. POTENTIAL TYPOLOGY APPLICATION IN VULNERABILITY AND ADAPTATION RESEARCH

The literature search described earlier identified a range of direct and indirect typologies that served different purposes including clarifying the complexity of specific phenomenon (e.g. categories of climate extreme – Schneider and Sarukhan 2001), providing clarity of meaning and understanding (e.g. categories of vulnerability interpretation – Kelly and Adger 2000), assisting in the identification of types of adaptation options (e.g. Smit and Skinner 2002), ranking and categorising places for prioritized attention and targeted interventions (e.g. Adger and Vincent 2005, Perch-Nielsen 2010) . However, there are limitations and gaps which provide opportunity for future typology work.

3.1 Limitations and potential

A limitation of most direct typologies is that there is no explicit account of how they were derived. Many of the relevant typologies presented in Table 2, seemed to have been constructed from a literature review and/or close expert knowledge of the authors on the domain for which the typology was constructed. In Bailey's classification of typologies, these direct topologies are conceptual or operational and follow deductive or a combined deductive-inductive approaches respectively. An explicit explanation of procedure and coverage of sources would enhance the validity, rigour and relevance of the typology for the intended application. This is important because a different set of assumptions, metrics and data sets on units of interest could yield different groupings. So an important question then becomes which are the stable members of each grouping (high, moderate and low vulnerability) and which members shift easily when the metrics, data sources etc are changed? This type of information could perhaps yield a useful measure of uncertainty, a significant concern which is easily propagated when multiple indicators are used to measure vulnerability and adaptive capacity (Adger and Vincent 2005).

The indirect typologies reviewed in this paper also have limitations. One limitation is that the categories generated are by products of the indicator application and often assigned through ad-hoc decisions (say the first 20 countries in vulnerability index ranking as the most vulnerable) with no clear verification of the practical differences of category boundaries. Rigour, validity, and practical relevance can be improved if authors recognise that they are generating typologies that need proper statistical techniques and ground verification.

Another limitation that needs substantial improvement is conceptual, methodological and empirical weaknesses of many climate change vulnerability indices that drive indirect typologies of places and peoples (Fussel, 2009, 2010). Table 5 shows serious issues on the robustness, validity and practical utility of indices-based vulnerability ranking and grouping of nations raised by several studies and summarised by Fussel (2009).

The typology work on the interpretation of vulnerability and approaches for its assessment is another area for improvement. Currently different categories or definitions of vulnerability are treated as simple differences in interpretation that arise as a result of the use of the concept across different fields of study including natural hazards, climate change, poverty and development (O'Brien 2007. However, O'Brien et al. (2007) brings to our attention that the categories of interpretation such as "outcome" and "contextual" vulnerability are not simple, but fundamental differences on how vulnerability is viewed and framed. They constitute different discourses to the climate change problem.

Table 5. A summary of comments and reviews on indices based vulnerability ranking and categories

Reviewer/ commenter	*Reviewed Indices of national –level vulnerability to climate change*	*Review/Comment on Vulnerability indices*
Brooks (2005)	General	Aggregated vulnerability indices generally cannot adequately consider special circumstances that make certain countries, or groups of countries, particularly vulnerable (or resilient) to climate change (Fussel 2009 drawing from Brooks et al 2005)
Eakin and Luers (2006)	General	"Ranking and comparing vulnerability across countries […] is challenged by everything from the quality of the available data, to the selection and creation of indicators, to the assumptions used in weighting of variables and the mathematics of aggregation. There are also problems in the interpretation of indices" (p. 377).
Eriksen and Kelly (2007)	Vulnerability (Downing et al. 1995), Index of Human Insecurity (Lonergan et al. 1999), Vulnerability-resilience indicators (Moss et al. 2001), Environmental Sustainability Index, (Esty et al. 2005), and Country-level risk measures (Brooks et al. 2005)	indices reviewed show "relatively little agreement regarding which particular countries are the most vulnerable, with only five countries ranked among the 20 most vulnerable in two or more of the studies and only one country ranked among the 20 most vulnerable in all three (p. 502). "a serious deficiency in existing studies, the limited testing and verification of indicators and of the validity of underlying conceptual frameworks" (p. 504). these indices can not provide reliable information on the level of vulnerability of nations that can assist prioritising for adaptation funding and intervention.
Gall 2007	Human Wellbeing Index (Prescott-Allen 2001), Predictive Indicators of Vulnerability (Adger et al. 2004) Disaster Risk Index - Socioeconomic components (UNDP/BCPR 2004), Environmental Sustainability Index (Esty et al.2005) Human Development Index (UNDP 2005), Prevalent Vulnerability Index (Cardona 2005) National Adaptive Capacity Index (Vincent 2007).	"significant shortcomings in the construction of most of the evaluated indices with particular gaps in empirical validity and methodological robustness" (p. vi). the human development index outperforms the more recent indices as a generic national-level index of social vulnerability to climate change (see Table 5) but that "all indices hover around low to medium scores" (p. 120).
Fussel 2009	21st century socio-climatic exposure (Diffenbaugh et al. 2007) Global distribution of vulnerability (Yohe et al. 2006) & Environmental Vulnerability Index -climate change subindex (Kaly et al. 2004)	Inappropriate for prioritizing international adaptation funding due to severe conceptual, methodological and empirical weaknesses. (p. 17)

This recognition of fundamental differences in the categories of interpretation of vulnerability has significant implications on the choice of assessment methodology. Such differences in meaning allude to fundamental epistemological differences. In the presence of epistemological differences, combining or integrating approaches, which have been widely recommended in the typology articles, becomes untenable or at least a difficult exercise. Therefore, significant work should be done to articulate the nature and relationships of the categories of interpretations and approaches. This is important particularly because choosing an assessment approach is not as simple as fitting the method to a vulnerability context of the unit of interest, but also an epistemological choice of how vulnerability is viewed and framed.

To facilitate the choosing of an appropriate vulnerability assessment approach, a parallel set of work is needed on the typology of vulnerability of various contexts. Vulnerability contexts will vary from place to place and in time, but there will be significant vulnerability dimensions such as geographic location, topography, socio-economic and political inequalities that will help identify categories of contexts. Fussel's (2007) study on vulnerability factors that form a matrix of internal and external domain by biophysical and socioeconomic dimensions to define a vulnerability context can be a good start to this effort.

Furthermore, lessons from a typology work in systems thinking and practice can assist in articulating epistemological differences in the various interpretations of vulnerability, vulnerability assessments as well as in developing the typology of vulnerability contexts. In the 1980's and 1990's, the field of systems thinking and operational research articulated the epistemological differences between hard, soft and critical systems approaches. It also identified generic categories of the problem context through a matrix of assumption about the nature of the system(s) embedding the problem or issue of concern (simple, complex) and the dominant characteristics of the relationships of key actors or stakeholders in the system of concern (unitary or pluralist) (Jackson and Key 1984). Some common systems methodologies were classified according to this matrix. The typology has been a useful guide to researchers and practitioners in defining a problem context and selecting appropriate approaches and methods (Jackson 1990).

3.2 Gaps and potential

We have identified certain gaps in the current application of typologies to vulnerability and adaptation assessment studies. One specific gap is the use of typologies to study the behavioural dimensions of vulnerability and adaptation. Many of the socio-economic indicators used in ranking and categorizing the vulnerability of places and communities are mainly structural and lack behavioural indicators. Structural factors such as capital holdings and access are essential to individual and community adaptive capacity and overall vulnerability to climate change. However, vulnerability and adaptation to climate change will be significantly affected by people's behaviour, style of learning, perception of wellbeing and their beliefs about climate change. There is significant work in cultural and behavioural typologies writ large that could potentially come into play within this field of climate change perception and behaviour (e.g. .Douglas 1978, Douglas and Wildavsky 1982, Thompson and Wildavsky 1990). There are only limited published work that have used cultural and behavioural typologies in the domain climate change (Thompson 1997, Pendergraft 1998; Thomas 2006; Hulme 2009) and we found none in the assessment of vulnerability and adaptation to climate change. Studies linking

typologies of "perceptions of reality" (e.g. egalitarian, hierarchical, individualist, fatalist) to policy decision making and the climate change debate could help understand the public's reluctance to accepting new climate change policies such as the carbon tax (Verweij et al. 2006). The ability to link risk perception typologies to climate change behaviour and beliefs is one area of future typology work that can be useful to tailor education, communication on vulnerability to climate change, to improve adoption of adaptive technologies as well as to design and deploy targeted adaptation plans. A typology work in the behavioural dimension of vulnerability and adaptation can also generate indicators that complement current estimates that are heavily dependent on structural indicators. This potential typology study can build on an existing significant body of typology work related to farmer behaviour and learning styles, risk taking and propensity related to adoption of different types of innovations such as new marketing and management ideas, natural resource management practices, as well as farming technologies.

Another gap is the lack of participatory building of typologies as communication and social learning tools that spur adaptation. Currently most typologies are the product of exclusive expert exercises. Through not participatory in its development, the vulnerability cube built by Lin and Morefield (in press) discussed in previous sections was constructed as a tool for communicating relative vulnerabilities of estuary communities. Participatory and negotiated processes in a typology construction would allow effective communication and learning about state and trend vulnerability as well as promoting collaborative adaptation. This type of participatory typology building needs some guiding principles and steps to ensure scientific rigour and validity as well as relevance and uptake by stakeholders.

4. CONCLUSION

The systematic classification or a typology of different units of interest is essential, given the complexity as well as multiplicity of concepts, views and phenomena related to vulnerability and adaptation to climate change. Typologies assist with reducing complexity, detecting patterns and groups, identifying gaps, tailoring communication, and prioritising resource allocation and interventions.

Currently there is limited direct and indirect typology work in the climate change vulnerability and adaptation sciences. While useful, most of the current direct typology studies have no explicit descriptions of methods and processes on how they are developed. Work that has engaged indicator-based assessments of vulnerability and adaptive capacity sometimes generate typologies or groupings of places and people as a by-product with no sufficient attention to the rigour and validity and the practical differences in meanings of these groupings. Furthermore there is still significant concern on the conceptual, methodological and empirical soundness of existing vulnerability and adaptive capacity indices.

In addition to these limitations, this research has identified gaps particularly related to a lack of typology studies in the behavioural dimension, such as types of climate change associated beliefs, risk and vulnerability perceptions, as well as participatory typology building that engage stakeholders. Therefore, there is substantial potential for improving existing typology work and building new ones through rigorous and participatory process to assist communication, social learning and action on vulnerability and adaptation to climate change.

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