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REVIEW ARTICLE

Valuing non-market economic impacts from natural hazards

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Abstract
Prioritising investments to minimise or mitigate natural hazards such as wildfires and storms is of increasing importance to hazard managers. Prioritisation of this type can be strengthened by considering benefit and cost impacts. To evaluate benefits and costs, managers require an understanding of both the tangible economic benefits and costs of mitigation decisions, and the often intangible values associated with environmental, social and health-related outcomes. We review the state of non-market valuation studies that provide monetary equivalent estimates for the intangible benefits and costs that can be affected by natural hazard events or their mitigation. We discuss whether managers can usefully call upon these available estimates, with a view to using the benefit transfer approach to include non-market values in economic decision frameworks. Additional context-specific non-market valuation studies are required to provide a more accurate selection of value estimates for natural hazard decision making. Decision making would benefit from considering these values explicitly in prioritising natural hazard investments.

Keywords Non-market values · Intangible values · Willingness to pay · Natural hazard mitigation · Prioritising investments

1 Introduction

Governments, businesses, and individuals invest substantially in measures to mitigate the impacts of natural hazards, to provide emergency responses, and to recover and repair damages. However, it can be challenging to judge the relative priorities of these different investments (Murphy and Gardoni 2007). Often strategies are set and investments committed without a full evaluation of the trade-offs involved. Important but difficult management questions include: (a) When and under what conditions is it more valuable to mitigate risks

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from different hazards, for example, from wildfires rather than storms, floods, earthquakes or tsunamis? (b) How should investments be balanced between risk mitigation, emergency response, and recovery (Minciardi et al. 2009)?, and (c) Is a particular investment in natural hazard management worthwhile from an economic efficiency standpoint (Florec et al. 2017)? Although economic questions such as these are not the only consideration when evaluating approaches to risk management, they are almost always considered in some way.

Economists use a range of tools and frameworks to provide insights into these questions, with benefit–cost–analysis (BCA) normally employed as the core integrating tool (Ganderton 2005). When evaluating the impacts from natural hazards and the reductions resulting from particular investments, it is important to recognise that there can be different types of economic consequences. One important distinction is between effects on market values and non-market values. Market values refer to values derived from goods or services that are bought and sold directly in markets. For these goods, we can typically observe the prices for which they sell, and see how these prices change as a result of changes in their supply and/or demand. Market prices can, with some assumptions, be taken as an indicator of the marginal value to society of the provision of the good.

Non-market values, in contrast, relate to benefits or costs for which there is no explicit market and therefore no observable price (Freeman et al. 2014).[1] Examples of non-market costs due to natural hazards include losses of human lives, impacts on human health, impacts on the aesthetics of a landscape, risks to threatened species, and damage to public recreational facilities (Markantonis et al. 2012). The particular non-market values that are relevant to a natural hazard will vary over time and by particular event, depending on its nature, its location, its extent, and its severity. In some cases, these values can exceed market values. However, because non-market values lack direct relationships to observable market prices and quantities, they can be difficult to quantify.

The absence of readily observable market values for non-market impacts increases the risk that important values will be neglected when decisions are made, possibly leading to decisions that reduce social welfare. For example, they may be omitted from BCA of policy actions, resulting in inaccurate assessments of the social value changes associated with alternative investments and policies (Meyer et al. 2013).

In response, economists have developed innovative methods for quantifying non-market values in monetary equivalent terms. Many different methods are available, with varying strengths and weaknesses (Johnston et al. 2002; Markantonis et al. 2012; Meyer et al. 2013; Freeman et al. 2014; Champ et al. 2017). A large literature on non-market valuation has been established over more than six decades, developing methodologies and reporting empirical applications. In the 1980s and 1990s, some of the methodological approaches employed, in particular contingent valuation, were treated with scepticism and controversy largely due to their increasing application in economic assessments of the damages caused by catastrophic events such as oil spills. This controversy led the US National Oceanic and Atmospheric Administration (NOAA) to form a Blue Ribbon panel of renowned scholars, including two Nobel Prize winners, to examine the reliability of some of the methods employed. The panel concluded that the methods were deemed reliable under certain conditions, and they provided advice and guidelines in their application (see Arrow et al. 1993). Since then, a large body of research has further refined these methodologies and evaluated their validity; acceptance of their use has grown; and most non-market valuation

[1] The literature on risks and hazards sometimes refers to non-market values as "intangible" economic effects (Markantonis et al. 2012).

methods are explicitly approved for inclusion in BCAs by economic agencies in many countries (e.g. Baker and Ruting 2014; Carson 2012; Griffiths et al. 2012; US EPA 2010; Johnston et al. 2017b; Bishop and Boyle 2018; HM Treasury 2018).

However, with a few notable exceptions, the use of non-market values in economic studies of natural hazards is still at an early stage, and their direct use to inform decision making by relevant agencies is even less common (Rogers et al. 2015). Our aim in this paper is to raise awareness, to prompt discussion, and to increase the access to existing research into non-market values relevant to natural hazards. Once these values have been quantified, they can be included when evaluating the costs and benefits of different natural hazard management strategies. Our review is scoped at an international level, so that the structure and findings are broadly applicable.

The paper is structured as follows: After a brief outline of the main methods for quantifying non-market values, our primary focus is on results from existing research that has quantified particular non-market values relevant to one or more natural hazards. We discuss the comprehensiveness of the literature on particular types of impacts in a variety of contexts and note significant gaps in coverage. Finally, we discuss practical issues, challenges, and opportunities to make greater and more beneficial use of non-market values in decision making for natural hazards.

2 Non-market valuation methods

Non-market valuation methods are used to estimate community impacts or preferences in monetary equivalent terms. Values are generally estimated as the sum of individuals' willingness to pay (WTP) for improving (or to prevent degrading) the quantity or quality of a non-market good or asset.[2] Values are measured as changes relative to a clearly specified baseline (Bockstael et al. 2000; Freeman et al. 2014; Johnston et al. 2017b). For a wildfire event, for example, non-market valuation methods could be used to estimate the benefits of a mitigation programme that reduces the average area of natural forest burnt by wildfire in a region. Such valuation requires information about the policy or programme that will be implemented (e.g. a prescribed burn plan), or the expected impacts of the policy or programme on the natural hazard, particularly in terms of the magnitude of the changes in the good being valued (e.g. reduction in hectares of forest burnt), and then ultimately how this good is valued (directly and indirectly) by different individuals in society.

The total economic value of a non-market asset comprises use and non-use value. Use values relate to actual, planned, or potential use of an asset, and can be either market or non-market in nature. All non-use values (also called passive use values) are categorised as non-market values and represent the satisfaction that people gain from the asset without physically using it in an observable way; for example, some people may gain satisfaction from the knowledge that the asset exists (existence value) or that it is being maintained or protected for future generations (bequest value), for others to use (altruistic value), or for the option to personally use it in future (option value).

[2] Sometimes, one may elicit "willingness-to-accept" (WTA) compensation for losses, although this measure is not used as often as WTP.

There are two broad groups of methods for non-market valuation: revealed-preference and stated-preference methods (Champ et al. 2017; Freeman et al. 2014).[3] Each available method estimates different components of total economic value: revealed-preference methods measure use values (see Sect. 2.1), while stated-preference methods can measure both use and non-use values (see Sect. 2.2) (Freeman et al. 2014; Champ et al. 2017). Hence, the most appropriate non-market valuation method to apply depends on the types of values that need to be measured (Olander et al. 2015). Comprehensive BCA for environmental policies or programmes typically requires input from multiple different non-market valuation methods; no one method is typically able to capture all relevant and affected values (Johnston et al. 2002).

2.1 Revealed-preference methods

Revealed-preference methods use information from markets associated with the asset or good being valued, or from observing people's behaviour in their use of the asset, to infer an individual's WTP (Bockstael and McConnell 2010). Among the most common revealed-preference approaches are the travel cost (or recreation demand) method and hedonic pricing methods. The travel cost method is commonly used to measure values associated with recreation. It examines how people with different travel costs use a resource differently, providing an inference of an individual's WTP for each visit (Freeman et al. 2014; Parsons 2017). These travel costs include monetary expenses like fuel costs, additional food expenditures, entry fees, and other onsite purchases, as well as non-monetary expenses, such as the implicit time cost for travel (Hanley and Barbier 2009; Parsons 2017).

Hedonic pricing analyses investigate how non-marketed characteristics of an asset influence its market value (Hanley and Barbier 2009; Perman et al. 1999; Taylor 2017). For example, this method can be applied to property markets to estimate the values for scenic amenity or recreational opportunities based on proximity to the coast or a forest. By examining the premiums that are paid for a house close to a desirable amenity (or reductions in prices due to disamenities such as hazard risks), relative to similar types of properties elsewhere, we can infer people's WTP for the non-market characteristics associated with the house. This approach has been used frequently to evaluate values related to flood risks, as capitalised in residential property values (Daniel et al. 2009). It is also possible that behaviour in insurance markets may reveal information about the values at risk from natural hazards, although relationships between insurance markets and values are often difficult to disentangle. Ex post, the amounts paid by insurance companies following disasters provide some information on the damages that occurred, although damage costs are not the same as economic value losses (Freeman et al. 2014; Dickie 2017). Wirtz (2013) provides evidence that losses due to natural disasters have increased significantly since 1950, but only a fraction of those losses are covered by insurance (Wirtz 2013). Penetration of insurance varies widely globally, but even in the US around 25% of homes are uninsured. This lack of insurance does not indicate that the losses are not valued, but that a combination of income constraints and risk preferences means individuals are not able/willing to pay the premiums demanded by the insurance industry to provide cover. The existence of government disaster relief that crowd out private insurance, or government subsidies that

[3] Rather than explaining in detail how non-market valuation studies should be conducted, we refer the interested reader to the references (particularly the textbook references) provided throughout Sect. 2.

can mask individuals' true WTP, make revealed behaviour through insurance markets not a full representation of private values (Kousky et al. 2018; Chivers and Flores 2002; Michel-Kerjan and Kunreuther 2011).

Where use values are important, revealed-preference methods are commonly applied because they are based on observed behavioural data, and thus are perceived by some as providing more credible value estimates than stated-preference methods that are based on survey responses (Bateman et al. 2002). However, where non-use values are also likely to be important, revealed-preference methods will not be sufficient.

2.2 Stated-preference methods

Stated-preference methods use surveys to ask individuals questions that infer their WTP to achieve an outcome, or their willingness to make trade-offs between different outcomes. Stated-preference methods have the advantage that they are able to estimate monetary estimates for total WTP including both use and non-use values, including values associated with possible future scenarios for which "revealed" behaviour is not currently observable. Common stated-preference approaches include contingent valuation, contingent behaviour, and discrete choice experiments (Bateman et al. 2002; Boyle 2017; Holmes et al. 2017; Johnston et al. 2017b).

Contingent valuation estimates the value of assets by directly asking individuals how much they would be willing to pay to implement a change or prevent an impact, or asking them to choose for or against a policy (e.g. that would reduce hazard risks) at a given price (Mitchell and Carson 1989; Hanley and Barbier 2009; Boyle 2017). For example, individuals might be asked how much they are willing to pay for the construction of a flood levee that will protect a residential area from flooding, or asked whether they would vote for the policy at a particular cost to their household (e.g. in increased annual taxes or fees).

Contingent behaviour is similar to contingent valuation, but instead of estimating WTP, it assesses how other measures of demand, commonly in terms of visitation rates, change in relation to hypothetical changes in the quantity or quality of an asset (Bateman et al. 2002). For example, individuals could be asked whether they would make more or fewer trips to a camping ground under different prescribed-burning scenarios which lead to different recreational and amenity outcomes for the campsite. Contingent behaviour approaches are often conducted jointly with travel cost models (e.g. Boxall and Englin 2008; Kragt et al. 2009). This enables estimation of the WTP per trip, calculated from the travel cost model, to be aggregated across the number of anticipated visitors under each contingent behaviour scenario to look at changes in value.

Discrete choice experiments are used to estimate how individuals make trade-offs between different outcomes or different features of an asset, including price or cost (Adamowicz et al. 1998; Bennett and Blamey 2001; Hess and Daly 2014; Holmes et al. 2017). Respondents are asked questions about, for example, different natural resource management programmes. Each programme would vary in its outcomes or attributes. One of the attributes that are usually included in the choice scenario is a cost for each programme. Survey respondents consider trade-offs between the levels of the attributes (including costs) and choose their most preferred programme. Incorporating cost into the trade-offs enables calculation of WTP for different outcomes or attributes. For example, a choice experiment could consider different versions of a prescribed-burning policy to estimate how people value changes in forest protection, housing protection, days of smoke haze, and quality of campsite amenity.

2.3 Other methods

Other types of valuation methods, such as averting behaviour methods, may also be directly applicable to natural hazards (Bockstael and McConnell 2010; Dickie 2017). These include methods that rely on observations of damage costs avoided, replacement costs, defensive expenditures, or costs of illness (e.g. Kochi et al. 2010; Moeltner et al. 2013). Methods such as these typically focus on costs rather than measurements of economic benefits. Although in theory these methods are directly relevant to many types of natural hazards, the assumptions and restrictions necessary for their use can limit applicability. In most cases, these methods are only able to provide upper or lower bounds on values, rather than best estimates (Dickie 2017). In other cases, estimates from these methods have no theoretical relationship to well-defined measures of economic value (Holland et al. 2010). Consider, for example, estimating the damage costs to houses affected by a flood; these costs indicate the value of having to replace the housing materials, but do not account for the values associated with the stress and anxiety suffered by people who lose their homes and belongings, or the social disruption experienced by a community having to rebuild. Revealed- or stated-preference approaches could measure what people are willing to pay to avoid these inconveniences, over and above the cost of rebuilding the house. Accordingly, while cost-based approaches are easy to apply (see, for example, Shreve and Kelman 2014 who review cost benefit estimates from mitigation projects), they should be interpreted as a crude (and often highly inaccurate) proxy for the economic benefits of a policy or programme (Holland et al. 2010).

The life satisfaction approach has also recently emerged as an alternative to traditional revealed and stated-preference methods for non-market valuation (e.g. Luechinger and Raschky 2009; León and Araña 2015). In this approach, individuals rate their overall life satisfaction or happiness, and correlations are explored between this and explanatory variables such as changes in the condition of a non-market good following a natural hazard event. Income can also be included as an explanatory variable, enabling calculation of WTP by estimating the trade-offs implied by the coefficients for income and the non-market good relative to life satisfaction. Although these methods have been promoted by some researchers, they are not yet widely accepted by economists as a means to estimate valid measures of value.

2.4 Benefit transfer

Benefit transfer makes use of value estimates from existing non-market valuation studies, rather than conducting new studies. The process takes the values estimated via the approaches described above for an existing study site and extrapolates those estimates to predict values for a new target site (Johnston et al. 2015a, b, 2018c). The complexity of the benefit transfer process varies depending on how well one can match the characteristics of a target site (and population) to the characteristics of a site from an existing study. The value transfer can be as simple as adjusting for inflation and exchange rate where the two study and policy contexts are almost identical, or it can involve calibrating the original values based on differences in the population, time, and scale of the asset being valued. Another option is to collate data from multiple studies and use statistical methods for meta-analyses to determine the values for the target site. Benefit transfer allows values to be estimated when primary valuation studies cannot be conducted, but are not as accurate as primary study valuation methods (see also Brouwer and Bateman 2005; Johnston and Rosenberger 2010; Kaul et al. 2013; Johnston et al. 2015a, b, 2018c). Transfers involving benefit functions and information synthesised from multiple studies are often—but not always—more acute than transfers of a single value from individual studies (Kaul et al. 2013; Rosenberger 2015; Johnston et al. 2018c).

Benefit transfer should be an ordered process that begins with a clear definition of the impact or change to be valued and the scale and context of the changes occurring, as well as the relevant populations (Johnston et al. 2018c). This should be followed by a systematic search to identify available studies that might provide source values or value functions, evaluation to select the most suitable of those studies and the transfer process that will be used, performance of any adjustments needed to extrapolate values or functions to the target site, and sensitivity testing to ensure that value estimates are reliable. In some cases, it is appropriate to transfer an aggregate value from a single study, such as a single estimate to capture the non-use values for biodiversity protection (assuming that this is the only non-market value of interest). In other cases, separate components for different values may need to be transferred; for example, when there are recreation, health, and biodiversity impacts, and no source study can be identified that values all of these impacts as a package. In these component transfer cases, care has to be taken to avoid double counting. This is best done by identifying a small number of the most important, independent effects so that they can be treated as additive components to be valued.

Policy analysts requiring value estimates—for example as part of a BCA—will typically begin by reviewing possible benefit transfer options and source studies. This initial review is designed to help with the initial scoping and screening process by (a) setting out a framework for considering the types of impacts and value estimates to consider and (b) providing an overview of the types of benefit estimates that are available for different impacts of relevance. A review of this type is important for three reasons, even if a primary study might eventually be conducted to estimate values. First, time, funding, and other constraints often preclude the use of primary studies for valuation, leaving benefit transfer as the only possibility to obtain needed values (Johnston and Rosenberger 2010). Second, a review of previous studies can help to demonstrate how value estimates might be scoped, and identify appropriate ways of conducting a valuation exercise. Third, a search of the literature can reveal the extent to which previous studies are available for benefit transfer. The analyst can then judge the potential for those values to be transferred, with adaption, to the policy situation, and the expected accuracy of the transferred values. Additional considerations about requirements for accuracy, funding and time constraints, and any limitations on sourcing values (e.g. whether international transfers are appropriate) then need to be made (Johnston et al. 2015a, b). Following this, one decides whether values can be sourced from other studies, or whether some primary valuation exercises are required. In cases where suitable source studies are not available, but it is not feasible to conduct a primary study, then the "missing" values should at least be flagged as a gap in the BCA.

3 Review of the non-market valuation literature for natural hazards

The development of non-market valuation techniques has been closely associated with the valuation of pollution and environmental quality changes for policy evaluation and natural resource damage assessment. For example, Smith and Huang (1993) review the use of hedonic pricing models to assess values for air pollution reductions over more than a 25-year span. The volume of valuation work is demonstrated in meta-analysis studies associated with topics such as reductions in pesticide risk exposure (Florax et al. 2005); mortality risk reductions (Lindhjem et al. 2011); improvements in water quality (Johnston et al. 2005, 2017a, 2018a; Van Houtven et al. 2007; Johnston and Thomassin 2010; Newbold et al. 2018); as well as meta-analyses of values for recreation (e.g. Zandersen and Tol 2009); forests (e.g. Barrio and Loureiro 2010); coral reefs (Brander et al. 2007; Londoño and Johnston 2012); wetlands (Brander et al. 2006; Ghermandi et al. 2010); and lakes (Reynaud and Lanzanova 2017). An updated review of meta-analyses such as these across the valuation literature is provided by Johnston et al. (2018a). Yet most studies are generally focused on chronic rather than acute levels of pollution or the values of conservation assets or ecosystem services generally rather than losses from disaster. Of the many thousands of studies in the valuation literature, a relatively small proportion directly addresses natural hazards.

To establish the relevant literature for this review, we first identified the main types of values that are relevant to natural hazard decision making. These were identified through consultation with natural hazard decision makers, reviews of the natural hazard management literature, and observations of the possible outcomes of hazard events defined through a series of hazard risk assessment workshops run by the Western Australian State Emergency Management Committee in 2016. Ten value types were defined and categorised under the headings of health, environment, or social values (Table 1).

Grounded in these value categories, we aim to selectively review and discuss key estimates of non-market values specifically related to natural hazards, rather than exhaustively address all works in the valuation literature that could possibly be linked to natural hazards in some way.[4] In many cases, the literature relates to the risk of wildfires, as this is an internationally important context. The literature also includes a large number of studies related to flooding or flood risks. However, for many types of values impacted by natural hazards, there may be few or no context-specific studies available: while thousands of non-market valuation studies exist, relatively few of these are conducted in the context of natural hazard decision making (e.g. Markantonis et al. 2012; Gibson et al. 2016). In those cases, we refer to studies in a more general context. While such general results can provide a first approximation of values in the natural hazard context, readers should keep in mind that people's estimation of values are often sensitive to the context in which they are elicited.

3.1 Health values

3.1.1 Physical health

Physical health includes mortality and morbidity, with the latter encompassing pain, injury, serious illness, and disability. In relation to mortality, there are many studies in

[4] An initial search was conducted in July 2016 (updated in October 2018) in Web of Science searching across the context-specific terms "natural hazard", "natural disaster", "wildfire", "bushfire", "flood", "storm", "earthquake", "tsunami" or "heatwave", with the terms "non-market valuation", "willingness to pay", "choice modelling", "choice experiment", "contingent valuation", "stated preferences", "revealed preferences", "hedonic pricing", "travel cost", or "contingent behaviour". This search returned 279 results. This was inclusive of texts that referred to other primary studies discussing non-market values of natural hazards but did not provide primary data themselves. This search, and relevant cited literature within the returned texts, was used to inform the selection of references included in this review.

Table 1 Ten value types that are affected by natural hazards and their mitigation, described in terms of the changes in final outcomes that might result from a hazard event or mitigation action

Value type	Examples of hazard event or mitigation outcomes
Health values	
Physical health	Change in the number of fatalities
	Change in the number of serious injuries, hospitalised injuries, and minor injuries
	Change in the number of illnesses or diseases
	Change in pain to individuals
Mental health	Change in reported cases of grief, stress, and anxiety
	Change in the number of fatalities (due to self-harm)
Environment values	
Ecosystems	Change in the number of flora and fauna species
	Change in the number of identified endangered species
	Change in the status of identified endangered species
	Change in native vegetation coverage Change in status of ecosystem function
	Change in status of identified threatened ecosystems
	Change in carbon storage in vegetation and soils
Water quality	Change in riparian vegetation coverage
	Change in the condition of waterways
Social values	
Recreation	Change in recreation activity within the area
Amenity	Change in scenic amenity in the area
Safety	Change in the perceived safety of a dwelling location or construction
Cultural heritage	Change in Aboriginal heritage significance
	Change in non-Aboriginal heritage significance
	Change in natural heritage significance
	Impact to sense of place
Social disruption	Breakdown of existing family and support networks, such as social networks
	Change in moveability, such as traffic and public transport
	Change in availability of basic services, such as electricity outage
	Number of displaced people away from people's homes and work places
Animal welfare	Displacement, death, or injury to animals

a non-hazard context that estimate the value of a statistical life (VSL). VSL is used as a measure of the benefit that would be generated by preventing a death.[5] For example, based on a literature review, the Australian Government recommends the use of AUD(2008) $3.5 million as a standard VSL in economic analyses of projects (Abelson 2008; Australian Government 2014). VSL has been estimated using both revealed-preference methods (e.g. Viscusi 2004) and stated-preference methods (e.g. Viscusi 2009; Carlsson et al. 2010a),

[5] Note the values estimated by VSL reflect the value of reducing the risk of an additional death that may occur over a large population, and not the value of any one particular person's life (Rittmaster et al. 2006).

and estimates generated by the approach have been shown to be sensitive to the method used as well as to the context and location of the study.

A review of 244 international VSL studies by Access Economics (2008) found that the mean VSL was AUD(2006) $9.4 million and the median $6.6 million. However, there was wide variation in point estimates with VSLs ranging from $0.1 million to $133 million depending on the country and the context. Average VSLs were highest when calculated in relation to the environmental protection sector, at $11.2 million, and lowest when estimated with respect to the health sector, at $4 million. Of the 14 countries for which specific VSL estimates were available, South Korea had the lowest mean VSL ($1.6 million). France and Japan had estimates above the average VSL, along with the UK which had the highest mean VSL ($17.5 million). The other countries included in the review were all below the mean VSL, including Australia, Austria, Canada, Denmark, Hong Kong, New Zealand, Sweden, Switzerland, Taiwan, and the USA.

Further evidence of VSL estimates being sensitive to context is shown by Viscusi (2009) who found that lives saved by reducing deaths from traffic accidents are valued almost twice as highly as lives saved by preventing natural disaster deaths in the USA, with the latter value estimated at US(2008) $2.99 million per life. Carlsson et al. (2010a) similarly find that the VSL for reducing lives lost due to fire and drowning, at SEK(2007) 13.2 million and 12.6 million, respectively, are one-third lower than for traffic accidents.

The differences in VSL related to context and location mean that it is preferable to use a VSL estimated for the specific country and natural hazard of concern, if possible. Based on the Access Economics (2008) review, the range in values is greater by country than by context. If a VSL estimate cannot be located for the relevant population *and* context, using a VSL for the relevant population, and calibrating for differences in context, is more important than prioritising a match in context.

The approach used to estimate VSL also has implications for the magnitude of the value. Access Economics (2008) found that the mean VSL for the revealed-preference studies in their sample was AUD(2006) $9.6 million, compared to the VSL for stated-preference studies with a mean of $11.2 million. This is consistent with the theoretical underpinnings of each method, where revealed-preference studies often provide lower estimates of value and could thus be considered as a more conservative approach (see Sect. 2). Which method to use is ultimately a choice of the researcher and decision makers.

Turning attention to other health impacts of natural hazards, there are studies that estimate values for morbidity. Morbidity describes a poor health state and can be broadly separated into conditions arising from disease, and those from injury. The morbidity effects from natural hazards include waterborne disease, respiratory disease, cancer, and stress-related disease, among others (Nohara 2011; Dohrenwend et al. 2013; Kochi et al. 2010). The welfare impact from morbidity varies depending on the severity and duration of adverse health outcomes (Kochi et al. 2010).

Most morbidity impacts from natural hazards that have been quantified in monetary or monetary equivalent terms are those related to wildfire smoke. The majority of studies that estimate the health cost from exposure to wildfire smoke use the cost-of-illness approach, a cost-based approach that measures the financial cost of treatment and not the benefits from avoiding the impact (which are broader than avoidance of financial costs) (see Sect. 2) (Kochi et al. 2010). For example, Moeltner et al. (2013) estimated the incremental treatment costs from the impacts of bushfire smoke for 350,000 residents in northern Nevada, USA. They accounted for distance to the fire, fuel load, and a 4-year lag in health effects, finding that average aggregate treatment cost for smoke-induced inpatients for this population was close to US(2008) $2.2 million (or an increase in treatment cost of $54 to $209 per affected person).

Given the limitations of the cost-of-illness approaches, WTP approaches provide a more accurate and complete representation of the total benefits generated by reducing morbidity from wildfire smoke. Richardson et al. (2013) found that the estimates of the benefits of a reduction in symptom days for a wildfire smoke-related illness were 30 times larger when using a WTP approach compared with a cost-of-illness approach: US(2009) $95 and $3.02 per person per symptom day, respectively, in California, USA. They also compared values estimated by the defensive behaviour method, which considers the costs associated with the actions people take to avoid exposure to the smoke. This method was more comparable to the WTP approach at $86.90 per person per symptom day.

Rittmaster et al. (2006) used both WTP and cost-of-illness approaches in a benefit transfer application to estimate the morbidity effects of the Chisholm fire in northern Alberta, Canada, in 2001, which burned 116,000 ha and caused a smoke plume that affected a population of 1.1 million. The additional morbidity risk associated with exposure to increased particulate matter levels was estimated at approximately CAD(1996) $9.6 million ($8.70 on average per person). Hospital admission and emergency room visit costs were calculated through transfer of values estimated by cost of illness, and other morbidity values, such as those associated with restricted activity days or asthma and respiratory symptom days, were calculated through transfer of values estimated by WTP approaches.

O'Donnell et al. (2014) conducted a choice experiment in Flathead County, USA, to estimate the WTP of households to avoid smoke days. Households were willing to pay US(2009) $13.30 and $2.34 to avoid an additional unhealthy or moderate smoke day, respectively, per fire season for the next 10 years. The values may be smaller in this study relative to those estimated by Richardson et al. (2013) because they refer to a smoke day which poses a risk to health, but does not necessarily result in illness, while Richardson et al. estimated values associated with the realised symptoms of a smoke day.

Beyond the smoke-related illness caused by wildfire, natural hazards can cause injury and pain. While no context-specific valuations exist for these physical health impacts, other out-of-context studies can provide a useful reference point. Hensher et al. (2009) estimate WTP to avoid a range of injury types in the context of road traffic accidents, from a sample of New South Wales vehicle drivers, Australia. They distinguish between the accidents occurring in urban or non-urban areas. WTP to avoid a serious injury, where extended hospitalisation is required and which may result in permanent disability, was estimated at AUD(2007) $310,000 or $194,000 per injury for urban or non-urban areas, respectively. For hospitalised injuries, where treatment in hospital is required but full recovery is expected, WTP was $75,500 or $56,900 per injury for urban and non-urban areas. For minor injuries where medical treatment was required, but no hospitalisation, WTP was smaller for urban areas at $16,500 per injury compared to non-urban areas at $20,300 per injury.

Chuck et al. (2009) also provide a useful reference point with respect to WTP for a reduction in pain. Individuals from Alberta, Canada, indicated they would be willing to pay CAD(2007) $361 per person per month to improve "disability caused by pain" to a mild condition, or $1070 per person per month to improve "pain intensity" to a mild condition.

3.1.2 Mental health

Substantial literature has been published regarding the psychological trauma and emotional impacts of bushfire and natural hazards, including not only the direct impacts of the event on mental health, but also the secondary and indirect effects on mental health resulting from stress, separation anxiety, failing relationships, and disintegrating friendships (Eriksen 2013). A variety of natural hazard studies list psychological problems and mental health impacts as "intangibles". These discussions frequently discuss the importance of acknowledging emotional or psychological impacts, but state that there are no agreed-upon methodologies for measuring these impacts (Handmer et al. 2002; Stephenson et al. 2013). Estimates of WTP values for changes in mental health states are not well documented in the non-market valuation literature. Gould et al. (2013) acknowledge the importance of including the cost of psychological trauma when determining the costs of wildland fires, but do not specify what values to use or how to measure those values.

As with morbidity, cost-based approaches have been used to estimate the cost of adverse mental health resulting from natural hazards. Dunn et al. (2003) addressed the cost of post-fire emotional trauma. They estimate the expenditure of non-profit agencies on providing social assistance to residents impacted by the 2003 Old, Grand Prix, and Padua Fire Complex in southern California, as being in the order of US(2005)$3.6 million. Unfortunately, this estimate does not separate post-fire emotional recovery efforts from home rebuilding recovery costs and does not report costs per household or per person.

Knowlton et al. (2011) discussed psychological impacts as well as the cost of lost lives and health impacts in relation to the 2004 Florida hurricane season in the USA. Using data for the 17.4 million people exposed, the additional healthcare costs of treating hurricane-related post-traumatic stress disorder was estimated at approximately US(2008) $57 million.

3.2 Environment

3.2.1 Ecosystems

Ecosystem valuation studies typically estimate values for changes to particular ecosystem conditions (e.g. Petrolia et al. 2014; Rajmis et al. 2009), changes to the species of flora and fauna that live within an ecosystem (e.g. Richardson and Loomis 2009), or changes in ecosystem services provided to human populations. There are many non-market valuation applications for ecosystem services in contexts related to natural hazards. For example, studies have estimated value changes related to the reduced risk of flood or storm damage as a result of maintaining healthy ecosystems such as wetlands, mangroves, and coral reefs (e.g. Barbier et al. 2011, 2013; Brander et al. 2006, 2013; Everard et al. 2014; Johnston et al. 2018b; van Zanten et al. 2014).

In their international review of 26 studies estimating the value of wetlands for different regulating services, Brander et al. (2013) report that the median WTP for wetlands providing flood control is US(2007) $427 per hectare per year (mean WTP was much higher, at $6920 per hectare per year). Using a choice experiment, Petrolia et al. (2014) estimated how much households across the USA were willing to pay to increase the level of storm surge protection in Louisiana through coastal restoration programmes. They found that respondents' WTP was US(2011) $149 as a one-off payment to increase the percentage of households protected from storm surge from 5% of vulnerable households to 30%, and

$151 to increase it from 5 to 50% of households. The diminishing marginal value between the increase to 30 and 50% is a common result in WTP studies and is consistent with economic theory: the more rare something is, the more people are willing to pay for a unit of it; the more common something is, or the more units that people are able to consume, the lower the value of each additional unit. Studying the protective services of wetlands in coastal Louisiana, USA, Barbier et al. (2013) report that increased wetland continuity or vegetation roughness can reduce property damages by between US$24 and $133.

There are many examples of non-market valuation efforts that estimate the value of protecting or preserving ecosystems themselves, as opposed to the services they provide. Most of these, however, are not in the context of natural hazards. In a choice experiment on climate-change mitigation, German residents were willing to pay (2006) €27.50 each per year to improve the resilience of the Hainich National Park against insect pests and storms from "medium" to "high" (Rajmis et al. 2009). In the context of fire protection, Gregory (2000) applied a multiattribute utility approach to estimate WTP for fish habitat protection within the context of options for forest fire control in Oregon, USA. Petrolia et al. (2014), in their evaluation of coastal restoration of Louisiana wetlands, found that US households were willing to pay US(2011) $909 as a one-off payment to restore 50% of land that would otherwise be lost due to processes such as erosion, storm surge, and sea level rise. Johnston et al. (2018b) report that households within two coastal US communities were willing to pay between US(2014) $1.28 and $12.53 annually per acre of coastal wetland protected from loss due to coastal hazards, compared to between $18.69 and $18.83 per acre of beach protected. Other papers estimate total WTP for an ecological restoration project that enhances both hazard protection and ecosystem conservation simultaneously (e.g. Brouwer and Bateman 2005 for flood control, or Gregory 2000 for fires). In such cases, it is typically impossible to disentangle WTP for hazard reduction from that for other programme outcomes.

With respect to species living within ecosystems, there are numerous studies that aim to estimate the non-market values of threatened or native flora or fauna. As above, however, relatively few of these studies are framed within the specific context of natural hazards. An example is the study of Loomis and Gonzalez-Caban (1998), which estimated that residents in California and New England were willing to pay US$56 per household per year for a fire management plan that would result in 2570 fewer acres of critical habitat for spotted owls being burned by catastrophic fire. Another example is Luisetti et al. (2011), which reports values associated with managed coastal realignment in the UK, including WTP estimates for the protection of vulnerable salt marshes, where Essex residents were willing to pay £1.11 per year per hectare of new salt marsh and £3.57 per year for five birds species to return to the Blackwater River region (currency year and duration of payment unstated).

Because of the non-use, non-market nature of species' values, nearly all studies in the broader literature estimate species' values using stated-preference methods (e.g. Aldrich et al. 2007; Blamey et al. 2000; Campbell 2008; Kotchen and Reiling 2000). While there exists a substantial literature on species valuation, it is difficult to draw inferences from this literature on average WTP for different types of species as the way in which species are described in the studies varies greatly. Much literature valuing preventing a loss of endangered species focuses very specifically on individual species in particular geographical regions or areas (Cerda et al. 2014; Chakir et al. 2016; Kaval et al. 2007; Johnston et al. 2015a, b; Loureiro and Ojea 2008). The rest of the literature typically deals with the loss of endangered species in more generic terms, such as number of species, percentage of area inhabited by species, physical area inhabited by species (Blamey et al. 2000; Kragt et al. 2016; Martin and Blossey 2012; Polyakov et al. 2015; Rolfe et al. 2000). Some studies describe species in terms of the quantitative number of individuals (Carlsson et al. 2010b; Morrison et al. 1998), with others using qualitative descriptors of a species' status (e.g. conserved versus extinct—Campbell 2008). Some studies estimate WTP for preventing a loss of endangered species (Aldrich et al. 2007; Blamey et al. 2000; Campbell 2008; Kotchen and Reiling 2000), while others look at WTP for maintaining or increasing the presence of rare species (Choi and Fielding 2013; Kragt and Bennett 2011; Subroy et al. 2018).

Given the variability of WTP estimates and the way in which they are defined, meta-analyses are a useful means of drawing comparative inferences from the broader valuation literature. Ojea and Loureiro (2011), for example, conduct a meta-analysis of values related to biodiversity conservation, including some linked explicitly to natural hazards. Loomis and White (1996) and Richardson and Loomis (2009) provide the only published meta-analyses of the economic value of rare and endangered species, focussing on studies in the USA. They showed that households' WTP varies greatly depending on what type of species is being valued. For example, WTP estimates for marine mammals and birds were significantly greater than WTP for other species such as land mammals and reptiles (Loomis and White 1996; Richardson and Loomis 2009). Average one-off WTP was highest for the bald eagle (US(2006) \$297) and humpback whale (\$240), and lowest for species such as the Arctic grayling (\$23) (Richardson and Loomis 2009). These studies included in the meta-analysis measured WTP in a variety of ways (e.g. gains/losses of individual animals, protecting species habitat), so it is unclear how these figures precisely compare to one another. Other factors that increased the value attached to a species were larger changes in the size of the species population, if the species was charismatic, and if the species had both use and non-use values as opposed to non-use value only (Richardson and Loomis 2009).

3.2.2 Water quality

Like values for other types of environmental changes, WTP for water quality improvements is not commonly elicited in the context of natural hazards. Estimates of WTP exist to prevent water quality reduction caused by algal blooms (Roberts et al. 2008), stormwater runoff (Londoño Cadavid and Ando 2013), and contamination of drinking and surface water related to wastewater overflows (Veronesi et al. 2014). Roberts et al. (2008) found that people were willing to pay at least US(2006) \$3.87 per visit to Tenkiller Lake in Oklahoma to avoid the occurrence of an algal bloom during the visit, where the bloom was caused by nutrient runoff in high-rainfall events. Londoño Cadavid and Ando (2013) estimated WTP for improvements in water infiltration, which was described to respondents as a process that represented improvements in local environmental conditions through decreased runoff, increased water table recharge, and decreased fluctuation in water flow speeds and volumes. Households in Champaign–Urbana, Illinois, were willing to pay US(2011) \$0.49 per year for each 1% increase in water infiltration achieved by improved infrastructure for stormwater management. Veronesi et al. (2014) found that Swiss households were willing to pay up to (2010) CHF260 per year to avoid a change from medium ecological risks to very high ecological risks of flood-related wastewater overflow. Other studies estimate WTP for water quality improvements within the context of broader conservation programmes that simultaneously address natural hazard risks. An example is Bliem et al. (2012), which considers WTP for both water quality and flood control benefits of river restoration in the Danube basin. Keeler et al. (2012) discuss conceptual issues and challenges associated with the valuation of water quality in the context of natural hazards such as algal blooms, but do not provide empirical estimates.

Beyond natural hazard applications, there is an extensive literature evaluating the non-market values of water quality improvements (Bergstrom et al. 2001; Young and Loomis 2014), with thousands of publications to date. This literature is highly heterogeneous, reflecting the many ways in which different types of water quality improvements, in different areas and water bodies, benefit different user and non-user groups. Given the heterogeneity, there is a challenge in reconciling data and observations from different studies across the literature, so that valid inferences may be drawn.

Johnston et al. (2005) conducted a meta-analysis of WTP estimates for changes in water quality that affect aquatic life habitats.[6] They found over 300 studies on surface water valuation, of which 34 studies with 81 WTP observations from the USA were included in their meta-analysis. The smallest WTP value included was US(2002) $7.26 per household per year for a lake system in Minnesota—South Dakota—and the largest US(2002) $377 per household per year for freshwater systems in Colorado and North Carolina. Rolfe and Brouwer (2012) conducted a similar meta-analysis of WTP estimates to improve river health in Australia, drawing on 145 value estimates from 19 studies. The mean WTP of the 145 estimates was AUD(2010) $2.49 per household per kilometre of river in good health. These meta-analyses included studies measuring improvements in water quality that enabled protection of fish or other wildlife habitat, and enabled water-related recreational activity.

3.3 Social

3.3.1 Recreation

The best sources of data on recreation impacts resulting from natural hazards involve wildfires. Rausch et al. (2010) examined changes in trip frequency for campers in the Rocky Mountains, Canada, following a wildfire. Campers visited the eastern slopes of the mountains 2.56 times per year on average. If a wildfire affected the area, the visitation rate dropped to 1 visit per year, with the rate slowly increasing until it reached the pre-fire average 12 years after the burn. For a common type of camper, the WTP per trip was CAD(2004) $161, which equates to the lost value of each trip not taken after a wildfire. The average trip duration was 5.26 days equating to a value of $30.50 per day per camper.

The nature of how the forest regenerates after a wildfire appears to affect WTP to visit a recreational location. Using data collected via a permit system for Californian Wilderness areas between the years 1990–2004, Englin et al. (2008) found that visitors were willing to pay US$175 per hiking trip, on average. The value of a trip changed depending on the length of time since a burn occurred: the value increased significantly during periods of four to nine years after a burn and decreased significantly from 30 years onwards after the burn. Other time periods after the burn (<4 years and 10–29 years) had little impact on the value per hiking trip. The increase in WTP during the earlier time-period was assumed to be due to people's curiosity in the burned landscape, and the later decrease potentially related to the obstruction of view from the increasing density of the forest.

[6] This original meta-analysis has since been updated to incorporate variables that better capture spatial aspects of human populations and water quality changes (Johnston et al. 2017a, 2018a).

For the Mount Jefferson Wilderness area in Oregon, Brown et al. (2008) found that visitation rates did not change significantly after a major wildfire incident. Most recreationists (70%) did not change to a nearby substitute site after the fire. Comparatively, in the Canadian Shield region, Boxall and Englin (2008) found that backcountry recreationists who participate in wilderness canoeing experienced a loss in value due to disamenity one year after a burn along the canoe route, no difference in value 10 years after the burn, and an increase in value 30–65 years after the burn.

Rausch et al. (2010) noted that the per-trip value estimates in their Rocky Mountain study were comparable to values calculated for other similar recreational demand studies, such as Englin et al. (2008) in Californian Wilderness areas. It appears that travel cost values estimated for changes in recreational behaviour following natural hazard events, in particular wildfire events, are robust.

Clearly, the values estimated in these various studies are context-specific. The contextual differences in how visitation rates are changed following wildfire events mean that it is important to consider the temporal impacts of a hazard event on recreation. Hazard managers will need to be aware of the temporal changes in visitation to be able to aggregate measures of WTP appropriately. For example, in forests with a slow regeneration time after wildfire, such as those studied in Canada, there appears to be a decrease in visitation and subsequent loss in aggregate value for several years at least. In places like Australia, on the other hand, where fire-adapted forests regenerate relatively quickly after a wildfire, and where some plant species even require the heat and smoke chemicals to facilitate regeneration (Burrows 2008), one might expect visitation rates and values to only be affected for a short period of months or a few years after a burn.

Valuation studies have also considered how natural events might impact on recreation visits to water and beach assets. For example, changes in beach width due to erosion, storm damage, or flooding may affect recreational values. Whitehead et al. (2008) used a contingent behaviour stated-preference approach to estimate the increase in beach trip numbers if beach width were to increase, while Parsons et al. (2013) estimate a per-trip loss in recreational values of about US(2011) $5.00 per day for narrowing beaches to a quarter of their current width in Delaware, USA.

3.3.2 Amenity and safety

In the context of natural hazards, the value placed on visual amenity is often linked to values associated with risks imposed on an individual's life and property; thus, these value types are jointly discussed and estimated. Some people are attracted to live in areas that are more at risk from natural hazards, such as in forested areas, within flood plains, and on the coast, because of the high amenity values of these regions. Other people prefer to avoid these areas because of safety concerns. The use of non-market valuation methods to study amenity and safety in relation to bushfires, floods, and severe storms is common.

One particularly common set of applications includes the use of hedonic property value models to assess values associated with flood and/or erosion risks (or the reduction thereof) in residential areas, often but not always in the coastal zone. Gopalakrishnan et al. (2018) review the literature addressing coastal housing markets and risk. Because these studies apply a revealed-preference method, the resulting value estimates include only use values (non-use values are excluded). Examples include a large number of studies that evaluate the effect of Special Flood Hazard Area (SFHA) designation in the USA, based on Flood Insurance Rate Maps issued by the US Federal Emergency Management Agency. Examples of this work include Atreya et al. (2013), Bin and Landry (2013), Bin and Polasky (2004), Bin et al. (2008a, b), Kousky (2010), and Troy and Romm (2004). This literature generally finds that flood risk diminishes property values from approximately 0 to 11%, depending on context. Multiple studies have used quasi-experiments to estimate temporal trends of flood hazard effects, often in coordination with SFHA effects as discussed above (Hallstrom and Smith 2005; Carbone et al. 2006; Atreya et al. 2013; Bin and Landry 2013; Ortega and Taspinar 2018).

Among the challenges faced within this type of model is disentangling positive amenity effects of proximity to water (such as coastal views) with negative risk effects (Bin and Kruse 2006; Bin et al. 2008a). Bin et al. (2008a) develop an explicit Lidar-based viewshed analysis to offset this effect. Other studies explain potentially counterintuitive results based on an inability to address potentially confounding amenity effects, at least for some homes in the sample (Bin and Kruse 2006). A related but smaller strand of literature addresses the impact of beach width, erosion and nourishment on property values (Qiu and Gopalakrishnan 2018; Landry et al. 2003; Parsons and Powell 2001). Hedonic studies of this type typically estimate values that confound multiple types of economic loss due to beach retreat, including those related to natural hazards such as flooding.

Daniel et al. (2009) provided a meta-analysis related to reduced risk from flood hazards such as these. The meta-analysis uses 19 revealed-preference studies, with 117 observations, that estimate welfare values for reduced risk from flooding in the USA. They found that estimates of the marginal values of flood risk varied considerably. After controlling for observable and unobservable differences across studies, the marginal effect of an increase in the probability of flood risk by 1% in a year amounts to a difference in price of an otherwise similar house of −0.6%.

Stetler et al. (2010) estimated the value of reducing bushfires in terms of reduced risk and increased amenity. The authors used the hedonic pricing method to identify the effects of 256 wildfires and environmental amenities on property values in northwest Montana between June 1996 and January 2007. Proximity to and view of wildfire-burned areas had large and persistent negative effects on property values. Properties within 5 km of a wildfire-burned area experienced a 13.7% reduction in property values (US$33,200), and the values of those properties with a view of the wildfire-burned area were reduced by a further US$6610 per affected home.

Similarly, Athukorala et al. (2016) conducted a hedonic pricing analysis of property sales in wildfire-affected areas of Rockhampton in Queensland, Australia, finding that sale prices for properties in the affected region dropped on average by 6.1% or AUD(2016) $22,600 relative to properties in unaffected areas. Rajapaksa et al. (2016) found that prices for properties in flood-affected areas of Brisbane in Queensland, Australia, were also 6–7% lower for low- and high-income suburbs, respectively, than for unaffected areas.

There are a handful of studies on the value of reducing the risk of earthquake damage to life and property (Hidano et al. 2015; Naoi et al. 2009; Beron et al. 1997; Keskin 2008). For example, Hidano et al. (2015) found that between 2008 and 2012 property values in Tokyo, Japan, for zones with a low risk of earthquakes were between 14,000 and 17,400 JPY higher than for properties in high-risk areas, depending on the type of seismic risk. They also found that sales prices were not significantly affected by information about seismic risk for newly constructed earthquake-resistant apartments, providing evidence for the value of mitigation.

3.3.3 Cultural heritage

Impacts of natural hazards on cultural heritage can relate to changes in recreational use of heritage assets, in which case the recreational values discussed in Sect. 3.3.1 are applicable. However, values may also relate to protection of cultural heritage from natural hazards, including the existence values associated with such assets. There is a small literature on the values of cultural heritage, with very few studies on their non-use values. We are not aware of any studies that estimate values of cultural heritage in the specific context of natural hazards. The majority of research reports values for ex situ items (e.g. in museums) as opposed to in situ heritage—the latter being of particular interest in natural hazard management.

There is a study that assessed values for protecting historic sites that targeted risk of wildfire in forest areas of South Australia (Rolfe and Windle 2015). Visitors to forests with heritage sites were willing to pay AUD(2012) 0.11 *and* 0.54 for a 1% additional protection in two forest areas, with the higher value associated with a forest containing more heritage sites.There are two studies relevant to the value of protecting in situ Aboriginal cultural heritage. Both suggest that citizens are WTP to protect such resources in situ. For example, Rolfe and Windle (2003), found that the Aboriginal population of Rockhampton were willing to pay AUD(2001) $3.22 per household per year for a 1% increase in the number of Aboriginal cultural heritage sites protected in central Queensland (equating to 27 sites). However, this study was not undertaken in a natural hazards context. The second study of Aboriginal cultural heritage values focussed on resource *damages*. Boxall et al. (2003) studied recreation values associated with Aboriginal cultural heritage and vandalism along two canoe routes in Manitoba, Canada, enabling a comparison of WTP for trips where Aboriginal paintings were absent, in poor condition due to vandalism, or in pristine condition. They found that "pristine" paintings were valued between CAD(1995) $61.30 and $77.30 per trip, whereas vandalised paintings were valued at substantially lower levels between $3.96 and $8.39, relative to an absence of paintings. While the contextual differences make it difficult to extrapolate these WTP estimates to the specific impacts of natural hazards, the results demonstrate a positive value from cultural heritage, which will vary from the extent of damage to such heritage from hazard events.

3.3.4 Social disruption

The disruption of services that are important to the functioning of communities, such as electricity, schools, and government services, can cause a welfare loss to society. Paveglio et al. (2015) reviewed the social impact from wildfires and note that social disruption is a complex issue for which there is a lack of accessible, comprehensive, and uniform metrics. One of the complications is that social impacts are likely to vary by population characteristics. For example, communities in developed countries are likely to better manage and absorb disruptive community impacts relative to communities in developing countries.

Landry et al. (2007) provide one of few studies of social disruption values in a natural hazard context. They estimated WTP of New Orleans residents to return home following Hurricane Katrina. Individuals who were employed full time had an annual WTP to return home of US(2005) $3950. Using a choice experiment with Flathead County residents in California, O'Donnell et al. (2014) estimated that households have a WTP of US(2009) $0.24 to avoid an additional home evacuation due to wildfire, per year for the next 10 years. While these studies have radically different values of WTP, they likely reflect the differences in study context: the flood situation in New Orleans led to extended absences for many residents whose homes and communities were completely destroyed. In the case of Flathead County, less than 5% of the sample had experienced an evacuation order due to wildfire, and no homes had been destroyed by wildfire in the county since 1988. Thus, although survey respondents were informed that evacuation orders would be given because properties were in danger of being damaged or destroyed, it is likely that respondents did not perceive this damage or the duration of the absence to be extensive.

While there is minimal valuation research on the social disruption caused by natural hazard events, values from other contexts may be useful. Hensher et al. (2014) measured consumer WTP to avoid disruptions in electricity supply in Canberra, Australia. They found residential customers' average WTP to avoid a 1-h electricity outage was AUD(2003) $37.50 per event, while their WTP to avoid a 24-h outage was $73.40. The WTP based on length of the outage was in log form, meaning that an outage that lasted 2 h was less than twice as inconvenient as an extra outage that lasted 1 h. This is important, as power outages from natural hazards can be lengthy. Equally important to note is that WTP could be substantially larger for residents within natural hazard-prone areas, as electricity is often needed for running water pumps and charging mobile phones and radio batteries.

Other types of disruption include effects on the movement of people to their place of employment or socialisation, either through impacts on infrastructure, or supply chains. Wisetjindawat et al. (2017) analysed the impact of flooding on petrol supply chains in Queensland, Australia, but did so only in the context of physical impacts and the ability to restructure demand. They did not place a value on those changes. Kato (2018) undertook a formal analysis of the compensating variation associated with degrading a transportation network. But there are no studies that explicitly evaluate the costs of disruption to travellers as a result of natural disasters. There are meta-analyses that evaluate the value of time in the context of transport disruptions (e.g. Zamparini and Reggiani 2007; Shires and de Jong 2009), but an issue with these commuter studies is that they are likely to reflect marginal values that may not be representative of the wholesale disruption that would be implied by natural disasters.

3.3.5 Animal welfare

There are significant community concerns about the welfare of animals in natural hazards (Trigg et al. 2017). This relates to the values associated with the physical or mental well-being of individual animals, whether they are domestic pets, livestock, or native animals, as opposed to, for example, the values of protecting threatened species and communities—which relates to ecosystem-type values.

Studies valuing community preferences about animal welfare are often nested within broader topics such as sustainable agriculture, food production, farming systems, and food labelling, and these usually relate to ethical agricultural management practices rather than natural hazards. These studies may be useful to provide an indication of animal welfare values for livestock. For example, there have been several studies valuing improved production methods (focused on cage production with chickens and pigs), and a number of studies focused on food label attributes that include information about farm animal welfare. Most studies have been conducted in Europe, with a smaller number in the USA. Cicia and Colantauoni (2010) conducted a meta-analysis of 23 international studies, with 88 observations of consumer WTP for farm animal welfare. They determined that consumers were willing to pay a 14.06% premium over the baseline price for meat products for a label declaring respect for animal welfare.

With respect to native animal welfare, Bach and Burton (2017) explored visitor preferences regarding the interactions of humans with the wild dolphin population at Monkey Mia, Western Australia. They estimated that people were willing to pay AUD(2012) $35.30 per visit to avoid a 30% increase in dolphin calf mortality. A study on 110 dolphin calves in this region determined that 62% of 16 calves belonging to females who were regularly fed fish died by age 3, while 40% of the other 94 calves died (Mann et al. 2000). While we were unable to find studies directly estimating the non-market value of animal welfare in relation to natural hazards, these examples demonstrate that such values are held in other contexts.

4 The state of existing non-market values for decision making

While the review presented in Sect. 3 is non-exhaustive, it provides an overview of the literature that is available to provide monetary equivalent estimates of the types of non-market values that are often affected by natural hazards. Here, we summarise the issues to consider attempting to utilise these values (through benefit transfer) to inform decisions about natural hazard management. Efforts to assign values through a benefit transfer exercise should demonstrate there has been a comprehensive search for source values, so that the studies that have been selected can be justified as the most appropriate, and that any adjustments or extrapolations of values to account for differences between source study and target application is well justified (Johnston et al. 2015a, b). This requires a careful evaluation of existing studies to identify key factors influencing values. Where values are not available from other studies, or are not considered to be of sufficient accuracy, then primary valuation studies may need to be conducted.

Context and location are shown to be important factors in determining WTP for reduced natural hazard impacts. WTP for protecting physical health varies between countries and it depends on whether or not the context involves a natural hazard (Access Economics 2008; Carlsson et al. 2010a; Viscusi 2009). The method used to estimate non-market values also influences the estimated WTP. Cost-based approaches do not reflect the total economic benefits, and while revealed preferences provide a suitable estimate for use-related value, they only capture lower bounds of values where both use and non-use values are relevant.

The scope or magnitude of changes being valued is also important in determining WTP for hazard reduction or the amount of potential damages. Values are expected to vary with scope, including values that are transferred from other studies (Ojea and Loureiro 2011). Typically, WTP increases at a decreasing rate with increases in the amount or quantity of a good or amenity, consistent with diminishing marginal utility of additional units (Rolfe and Dyack 2011). These scope effects create challenges for benefit transfer, as value transfers are only relevant to the scope context where they have been derived; transferring marginal values for changes may not be appropriate when the stock of the good or the amount of change to be considered is substantially different (Johnston et al. 2015a, b). In such cases, primary valuation studies may need to be conducted. Similarly, spatial dimensions will influence economic values, including effects of spatial scale, distance, spatially varying substitutes, and related factors (Bateman et al. 2006; Schaafsma 2015; De Valck and Rolfe 2018). Decision makers who use existing value estimates in benefit transfer need to attempt to find the best match between context, geographical location, and the appropriate method to measure the relevant economic values at stake, in order to avoid generating large additional errors in the transferred values (Bateman et al. 2011; Johnston et al. 2015a, b). Where matches between available study contexts and the decision-making context are inexact, sensitivity analyses should be used to manage the variability in WTP that results from differences in context, location, and methodology. Meta-analyses of past valuation studies can also provide benefit functions that enable estimated values to be adjusted to characteristics of the policy context.

In some cases, there is a vast literature of non-market values available, but it is difficult to summarise the circumstances under which particular values are applicable for natural hazard decision making. For example, the literature on ecosystem values, particularly with respect to species values, is so variable with respect to how the element being valued is defined that there is no simple way to determine values appropriate for use in benefit transfer. Values for water quality are also highly heterogeneous. In these cases, it may be possible for decision makers to find case study examples for the geographical area they are evaluating that would be useful for benefit transfer, but careful attention must be paid to how the commodity is defined.

In other cases, the literature is consistent with respect to values, such as the literature providing travel cost estimates for recreational trips (e.g. Rausch et al. 2010). However, decision makers require a thorough understanding of their own hazard context and geographical location to be able to understand how a hazard event might affect visitation, and therefore the changes that visitors will make in aggregate over time in regard to the number of trips taken.

For some value types, there is insufficient representation of non-market values in the literature to be able to draw inferences regarding WTP related to natural hazard events. This is particularly the case for mental health, cultural heritage and animal welfare values. The usefulness of existing non-market estimates for natural hazard decision making in these cases might be questionable. In these cases, conducting a new study for the specific decision context could be desirable. As more context-, geographical- and culture-specific studies are conducted and reported, databases can be built to provide a library of values that can later be used, with more certainty, in benefit transfer. For example, in Australia, the "Value Tool for Natural Hazards" aims to provide a set of accessible non-market value estimates for natural hazard managers to use in decision making (Rogers et al. 2017). Other benefit transfer libraries also exist, such as the Environmental Valuation Reference Inventory (EVRI),[7] though this particular resource encompasses environmental and health values more broadly and does not provide a comprehensive representation of non-market value estimates that are specifically relevant for natural hazard decisions in particular locations.

Finally, with respect to using non-market values, it is important to note that while the ten categories defined in Table 1 represent distinct value types that should be considered in natural hazard decision making, there can be overlap between them depending on how they are measured and included in economic analyses such as BCA. It is critical to consider any overlap to avoid the double counting of benefits or costs. For example, benefits might be described in a variety of ways along different stages of a causal chain of events, or relationships may exist between different value types. For

[7] See: https://www.evri.ca/en.

example, where values for *cultural heritage* are use-related, they could overlap with other values associated with *recreation*. In such cases, the analyst may wish to focus on the "final" values (similar to the highest trophic level in ecology) or on the "input" values, but not both.

5 Discussion

This review of non-market values illustrates that there are multiple value types that might be affected by natural hazards; that methods exist to measure these values in quantitative, monetary equivalent terms; and that these values can be large but are not always so. The importance of explicitly accounting for these values in natural hazard decision making is apparent. This can be done, for example, through inclusion in decision frameworks such as BCA (e.g. Florec et al. 2017). Studies that have estimated the damage costs of natural hazards highlight the magnitude of non-market costs (e.g. Deloitte Access Economics 2016), highlighting that a priority should be placed on capturing the non-market benefits of investments that mitigate natural hazards.

However, application of non-market valuation, and use of non-market values in decision analyses, must be undertaken with care, as the methods for estimating these values are not without their limitations and challenges. Some of these relate to practical issues, such as the fact that decision-making bodies may lack the time, budget, or capacity to commission or utilise the results of a non-market valuation study (Rogers et al. 2015). Others challenges relate to the theoretical basis of the methods, or the rigour with which they have been applied. For example, in travel cost models there is debate over whether opportunity cost of time should be valued at a person's wage rate, a portion of their wage rate, or for those who enjoy the travel itself, if travel time should be valued as a benefit instead of a cost (Hanley and Barbier 2009; Perman et al. 1999). In hedonic models omitted variable bias can occur when characteristics the researchers did not include in the price function play a larger role than anticipated, and some property characteristics may be related to each other leading to issues of multicollinearity or autocorrelation which can distort estimated values (Hanley and Barbier 2009). The hypothetical nature of the questions asked in stated-preference surveys can (but need not always) lead to various forms of response bias, for example, where respondents might not respond truthfully because the decision and its associated outcomes are not real, leading to over- (or under-) estimation of WTP (Bateman et al. 2002; Johnston et al. 2017b).

In considering the question of whether one should consider non-market values in strategic decision making, we make the following observations.

(a) If information about non-market values is omitted from decision processes that are informed by economic decision support tools (e.g. BCA), then an implicit assumption is being made that those values are zero, and that there is no variation in the non-market values generated by different decision options. These implicit assumptions are highly likely to be incorrect in most situations. Indeed, the literature reviewed here shows that the magnitude of some non-market values is large, particularly when aggregated over an affected population. Even if there is a degree of inaccuracy, it is highly likely that use of carefully considered positive values will be more accurate than assuming the values are zero. Where decision processes are not informed by such support tools, the omission of non-market values means that the decision maker makes an inference about the value, which could be zero or some other amount, but that inference generally will not be transparent.

(b) While an active debate over the validity and application of non-market valuation continues (e.g. Haab et al. 2013; McFadden and Train 2017), and biases exist that challenge the application of non-market valuation studies, many of the issues can be addressed to some degree through careful survey design and statistical analysis (Holland et al. 2010; Johnston et al. 2017b; Loomis 2011). Having non-market values associated with natural hazards in hand at least provides some recognition that they are important, and could be included in a BCA.

(c) There is uncertainty about all of the types of information needed for strategic decision making about natural hazard management, including biological and physical information. For example, there is often high uncertainty about the effectiveness of specific management practices at delivering the desired benefits. From our experience conducting BCAs for managers and policy makers in a range of contexts, uncertainty about non-market values is often less than the uncertainty about core biological or physical information that is routinely used in decision making. Given this, there seems no justification for excluding information about non-market values on the grounds that its accuracy is not assured.

(d) Accuracy of the information used may not be the most critical factor determining the outcomes delivered by a decision process. Pannell and Gibson (2016) found that the design of the decision process that used the information makes a much greater difference to the decision outcomes than the quality of the information used in an analysis of environmental management options. Decision processes that used accurate information but failed to account for basic economic principles performed far worse than sound decision process employing highly uncertain information.

(e) There are well-developed strategies for dealing with information uncertainty in decision processes. Sensitivity analysis allows for practitioners to test the robustness of their judgements about the relative merits of different decision options, and to explore the extent to which uncertainty about different variables affects the ranking of decision options (Pannell 1997).

There are alternative approaches to measuring non-market values for decision making. Non-economic approaches include: consultative methods, which involve administering structured questionnaires or interviews to gain an understanding of an individual's perceptions of an issue; and deliberative processes, which use group-based participatory methods such as focus groups, citizen juries, and Delphi surveys to elicit in-depth information about participants' relationships with the asset of focus (Christie et al. 2012). There also exists the potential for a government minister to make a judgement about non-market values, without using a consultative or deliberative approach. These approaches are not appropriate for generating monetary equivalent measures of non-market values for use in economic decision support tools.

Analytical methods such as multicriteria analysis (MCA) can include intangible values but do not monetise them. MCA has been strongly criticised for its lack of consistency with economic principles (Dobes and Bennett 2009). Arguably, non-market valuation studies provide a superior way of determining the weights that should be placed on intangible factors than the highly subjective small group processes that are often employed in MCA.

Given the value of being able to make trade-offs between market and non-market values, the importance of being able to prioritise public investment decisions, and the need to establish strong business cases for public investments, we have found that environmental decision makers in Australia are increasingly interested in the potential to utilise non-market valuation approaches as part of an evidence-based approach to decision making (Rogers et al. 2015; Gibson et al. 2017). Our recent experience in working with natural hazard decision makers in Australia suggests that this interest is spreading (e.g. Maqsood et al. 2017). This review enables decision makers to become familiar with the types of non-market values that are important for natural hazard investments and the range of value estimates that exist. We recommend that, where practicable, original non-market valuation studies are conducted to estimate values, particularly for important and expensive decisions. However, this review shows the potential for application of benefit transfer in natural hazard decision making.

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