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Valuing ecosystem resilience

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Abstract

The concept of ecosystem resilience is being increasingly discussed as a driver of biodiversity values. It implies that marginal deteriorations in ecosystem conditions can abruptly result in non-marginal and irreversible changes in ecosystem functioning and the economic values that the ecosystem generates. This challenges the traditional approach to the valuation of biodiversity, which has focused on quantifying values attached to individual species or other elements of ecosystems. As yet, little is known about the value society attaches to changes in ecosystem resilience. This paper investigates this value. A discrete choice experiment is used to estimate implicit prices for attributes used to describe ecosystem resilience using the Border Ranges rainforests in Australia as an example. We find evidence that implicit prices for the attributes describing ecosystem resilience are positive and statistically significantly different from zero.

Key words: ecosystem resilience, discrete choice experiments, implicit prices, willingness to pay space

1 Introduction

To ensure that investments in biodiversity conservation are appropriately targeted, information on the biophysical response of ecosystems to policy investments is required. So too is information on the values society enjoys from biodiversity conservation. Information on values helps to verify the case for biodiversity conservation investments and to target those investments to community priorities. Yet little is known about these priorities and the values that underpin them. Economic studies of biodiversity value have, to date, been primarily focused on what society is willing to pay to protect specific species, species diversity, ecosystem functioning, and the quality of habitats (see, for example, Christie *et al.* 2006; Czajkowski *et al.* 2008). Such studies have not accounted for aspects of risk facing ecosystems that are critical to the management of biodiversity. This omission has come to prominence with the emergence of the concept of ecosystem resilience. Ecosystem resilience against current or future threats is being increasingly discussed as a driver of biodiversity values. The concept of resilience implies that marginal changes in ecosystem conditions can abruptly result in non-marginal and irreversible changes in ecosystem functioning, and the economic values produced by the ecosystem. Hence the protection of biodiversity provides insurance against non-marginal and irreversible changes of economic value.

Hitherto, little is know about the value society attaches to ecosystem resilience. This paper investigates this value using a discrete choice experiment. To our knowledge, this is the first study to use a discrete choice experiment to estimate directly the value of ecosystem resilience.

In any discrete choice experiment respondents need to understand the information provided in the survey material. Otherwise, in an extreme case, respondents may make choices that are devoid of information about their preferences or reject participation altogether.

Communicating a complex concept such as ecosystem resilience in a choice experiment questionnaire poses a notable challenge. Hence, the first aim of this paper is to investigate respondents' understanding of the concept of ecosystem resilience as presented in the questionnaire.

The second aim of this paper is to estimate implicit prices for a set of attributes used to describe ecosystem resilience:

(1) probability of an ecosystem remaining in its current stable state (percentage);

(2) reversibility of an ecosystem shift (yes/ no);

(3) time period over which there is an increased probability that the ecosystem remains in its current stable state (years); and,

(4) area over which there is an increased probability that the ecosystem remains in its current stable state (hectares).

The estimation of implicit prices for these attributes enables the calculation of willingness to pay (compensating surplus) for a marginal change in ecosystem resilience as characterized by changes in the levels of the attributes. Information about implicit prices and compensating surplus enhances the understanding of the economic importance of biodiversity.

The reminder of this paper is organized as follows. The next section reviews the literature. After establishing a definition of ecosystem resilience we discuss its economic relevance as well as existing valuation approaches. This is followed by an overview of the research methods and the description of the empirical application. Finally, we report and discuss the results and draw conclusions.

2 Literature Review

Ecosystem resilience against current or future threats is increasingly discussed as a concept underpinning biodiversity values. Holling (1973) suggested that '[…] resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist'. Following Holling, Walker *et al.* (2004) define ecosystem resilience as '[…] the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks […]'. This definition implies that disturbance exceeding this capacity causes an ecosystem to cross a threshold beyond which a different stable state predominates – an ecosystem shifts from one stable state to another.

Biodiversity and its ability to support ecosystem processes are key determinants of ecosystem resilience (Chapin et al. 1997; Drever et al. 2006; Hooper et al. 2005; Thompson et al. 2009). A range of studies emphasize the importance of functional diversity (see, for example, Chapin et al. 1997; Diaz and Cabido 2001; Hooper et al. 2005), functional redundancy (see, for example, Diaz et al. 2003; Hooper et al. 2002) and response diversity (see, for example, Chapin et al. 1997; Elmqvist et al. 2003) in explaining the capacity of ecosystems to absorb stress without changing into an alternative stable state.

Using Walker *et al.'s* (2004) definition, ecosystem resilience can be quantified as the probability of an ecosystem shifting from one stable state to another, or alternatively, as the probability of an ecosystem remaining in its current stable state. Scheffer and Carpenter (2003), Walker and Meyers (2004), and Walker *et al.* (2010) give a detailed discussion about the theory of system shifts and the role of thresholds. In general, the probability of a system shift is determined by the present state of the system and the stress potential. The lower the ecosystem resilience the higher is the probability of an ecosystem shift (Walker et al. 2010).

Ecosystem resilience, in turn, may be reduced by marginal or non-marginal changes in the magnitude, frequency, and duration of disturbances (Folke *et al.* 2004). Disturbances may be caused by land use changes and pollution for example. They are reflected in altered fire and water regimes and habitat degradation, fragmentation and loss (Folke et al. 2004). Such changes then disrupt movements of organisms and ecological processes as well as reduce population sizes. The resulting alteration in the species mix, again, affects the main drivers of ecosystem resilience: functional diversity, functional redundancy, and response diversity (Folke et al. 2004). Put simply, changed disturbance patterns may increase the vulnerability of ecosystems. Stress that previously could have been absorbed now results in a (reversible or irreversible) shift of the ecosystem from one stable state to another. Consequently, an ecosystem passing a critical threshold may suddenly shift from a desired to less desired stable state. Ecosystem goods and services generated in the former stable state may not be available in the latter (Desgupta and Mäler 2003). Decreasing ecosystem resilience may thus lead to decreased economic value. In this way, biodiversity provides insurance against non-marginal and irreversible changes of economic value.

Few studies have estimated the economic value of ecosystem resilience. Perrings and Stern (2000) use an econometric approach (non-linear Kalman filter) to estimate reductions in the long-run productive potential of the agro-ecosystem due to losses in the resilience of agro-ecosystems in Botswana from 1965 to 1993. Their results suggest a small reduction in resilience during the drought period in the 1980s.

Mäler (2008) and Walker *et al.* (2010) use a probabilistic approach in a world with two alternative stable states of an ecosystem to determine what they define as an 'accounting price of resilience'. By assuming that a change in ecosystem resilience in the current time period will influence the probability of an ecosystem change in the future, they define the 'accounting price of resilience' of an ecosystem as the first derivative (with respect to a change in the stock of resilience) of the expected value of the discounted future net values. Implementing this approach requires information about the probability of an ecosystem shift and the net values generated under the two different ecosystem states.

An alternative approach is to estimate the value of ecosystem resilience directly by applying the discrete choice experiment method. This method asks respondents to make trade-offs between characteristics that describe non-market goods and services. These characteristics, or attributes, take on different levels and are bundled in choice options, which are offered to respondents in choice sets. The discrete choice experiment method provides information about whether the attributes used to describe a good or service are significant determinants of respondents' preferences. It also facilitates the estimation of monetary values of changes in the provision of a particular attribute (implicit prices), and thus allows the estimation of willingness to pay for a policy change (see, for example, Birol and Koundouri 2008; Hanley and Barbier 2009). Discrete choice experiments are widely used to estimate willingness to pay for environmental goods and services. Birol and Koundouri (2008) detail some European examples while Bennett and Birol (2010) provide developing country case studies. Numerous examples have estimated biodiversity values (see, for example, Christie et al. 2006; Czajkowski et al. 2008).

Despite these possibilities, economic studies of biodiversity value have, to date, been primarily focused on what society is willing to pay to protect specific species, species diversity, ecosystem functioning, and the quality of habitats. Values of ecosystem resilience have mostly been ignored. To our knowledge, the study presented in this paper is the first to explore the value of ecosystem resilience directly using a discrete choice experiment.

The direct estimation approach poses some challenges, one of which is directly related to the complexity of the concept of ecosystem resilience. As in any discrete choice experiment, it is crucial that participants understand the information that is provided in the survey questionnaire. Otherwise, in an extreme case, respondents may make choices without revealing any information about their true preferences or reject participation altogether. As outlined before, ecosystem resilience involves the concept of probability – an abstract and intangible concept that is difficult to explain to many respondents. The first aim of this study is therefore to explore whether it is possible to communicate a complex topic such as ecosystem resilience by means of an internet delivered choice experiment questionnaire. This is reflected in the following research questions:

1. Do respondents understand the concept of ecosystem resilience, and are thus capable of making informed choices in a choice experiment survey?
2. Does the level of education influence preferences for ecosystem resilience?

The second aim of this study is thus to investigate peoples' preferences for ecosystem resilience using the following research questions:

3. What are the implicit prices of attributes used to describe ecosystem resilience?
4. What is the willingness to pay (compensating surplus) for improvements in ecosystem resilience?

3 Methods

To explore respondents' understanding of the concept of ecosystem resilience, follow-up questions were included in the questionnaire. Respondents were asked to indicate on a five point Likert scale whether they agreed with the following statements:

(1) 'I understood all the information provided.'

(2) 'I understood the descriptions of the alternative management options.'

To investigate whether the complexity of the concept of ecosystem resilience resulted in sample selection bias the sample's educational characteristics were compared with the census data provided by the Australian Bureau of Statistics (2006). Respondents were categorized as: (1) 'Postgraduate Degree', (2) 'Graduate Diploma and Graduate Certificate', (3) 'Bachelor Degree', (4) Advanced Diploma and Certificate', (5) 'No Non-School Education'.

A discrete choice experiment was used to estimate willingness to pay for an improvement in ecosystem resilience based on implicit prices. Commonly, implicit prices for attributes are derived by calculating the ratio of estimated distributions of non-cost and cost parameters obtained from a choice model defined in utility space. This approach, however, can lead to unreasonable high or low mean estimates for implicit prices if the estimated value of the cost parameter denominator is close to zero. Fixing the cost parameter or constraining parameter distributions may help overcome this limitation but imposes other restrictions. A fixed cost parameter implies firstly that the marginal utility of money is homogeneous across respondents, and secondly, that the scale parameter is the same across all observations; a constrained distribution truncates preference heterogeneity (Hensher and Greene ; Scarpa *et al.* 2007).

These limitations can be avoided by estimating implicit prices directly in willingness to pay space. In this study, utility is specified in willingness to pay space with respondent n choosing between J alternative management options in each of the S_n choice sets offered in a repeated choice format. Following Scarpa *et al.* (2007), the utility function in willingness to pay space is defined as:

$$U_{njs} = -c_n z_{njs} + (c_n w_n)' x_{njs} + \varepsilon_{njs} \quad (1),$$

$$w_n = a_n / c_n \, , (2),$$

with non-cost coefficients a, cost coefficient c, cost attribute z, non-cost attributes x, and an i.i.d. Gumbel distributed error term ε.

The collected data were analyzed using a panel mixed logit model assuming normally distributed and freely correlated random parameters (Revelt and Train 1998). Letting β_n denote the random parameters within the utility function specified as c_n[1] and w_n, utility can be written as $U_{njs} = V_{njs}(\beta_n) + \varepsilon_{njs}$, where $V_{njs}(\beta_n)$ are defined by equations (1) and (2). Respondent n chooses management option i in choice set t if $U_{nis} > U_{njs} \forall j \neq i$. The conditional probability of respondent n's repeated choice can be expressed as:

$$L(y_n \mid \beta_n) = \prod_{s=1}^{s=S_n} \frac{e^{V_{ny_{ns}s}(\beta_n)}}{\sum_j e^{V_{njs}(\beta_n)}},$$

Where y_n represents the respondent's repeated choice over S_n choice sets as $y_n = (y_{n1}, \ldots, y_{nS_n})$ and y_{ns} represents the management option chosen by the respondent in choice set s. The unconditional probability can be expressed as:

$$P_n(y_n) = \int L(y_n \mid \beta_n) g(\beta_n) d\beta_n,$$

with $g(\cdot)$ denoting the density of β_n.

The model was estimated with Biogeme 2.0 using maximum simulated likelihood[2].

To examine whether the respondents' education had any statistically significant impacts on implicit prices we included effects coded variables representing non-school education levels into our model. For this purpose, the data were regrouped into three categories: (1) 'Advanced

[1] To ensure a negative sign of the cost parameter estimate, c_n enters the utility function as $-\exp(c_n)$.

[2] 1000 Halton draws using the 'BIO' algorithm available in Biogeme 2.0.

Diploma and Certificate', labeled *education_1,* and (2) No Non-School Education', labeled *education_2,* (3) 'Postgraduate Degree', 'Graduate Diploma and Graduate Certificate', and 'Bachelor Degree', labeled *education_3*.

4 Empirical application

Marginal willingness to pay for ecosystem resilience was explored using the case study of rainforest management in the Border Ranges, Australia. The Border Ranges region covers about 1,500,000 hectares and stretches from the south of Queensland (Beenleigh) to the north of New South Wales (Evans Head) and inland to Warwick. About twelve per cent (172,600 hectares) of the Border Ranges region is covered with different types of rainforest including subtropical, warm temperate, cool temperate, dry and coastal rainforest, and semi-evergreen vine thickets. The rainforests of the Border Ranges are recognized as a 'biodiversity hotspot'. Detailed information about the Border Ranges rainforests is given by the Department of Environment, Climate Change and Water NSW (2010).

An internet based survey was used to collect the data by drawing a random sample of the population of Brisbane from an internet panel[3,4]. The survey material was composed using expert opinion, focus groups[5], and a pilot survey[6]. The questionnaire asked respondents to make a sequence of five choices between three alternative options regarding the management of the ecosystem resilience of the Border Ranges Rainforests: one 'no new management actions' option at zero cost that was available in all choice sets, and two 'new management

[3] The main sample consists of 1,941 respondents of the population of Brisbane at the age of 18 and above. Only permanent residents of Australia and Australian Citizens qualified. The survey was online from 01.11.2010 – 30.11.2010.

[4] Number of respondents invited to participate: 11,513; number of respondents participated but not qualified: 1,502; number of respondents participated, qualified but not completed: 444; number of respondents participated, qualified but completed under 5 minutes: 385; number of respondents participated, qualified and completed in 5 minutes or more: 1,941.

[5] We conducted three focus groups with 12-15 participants each.

[6] The pilot sample consisted of 50 respondents.

actions to improve ecosystem resilience' options at non-zero costs. A choice set example is given in Figure 1. The options were described by five attributes as outlined in Table 1.

Figure 1: Choice set example

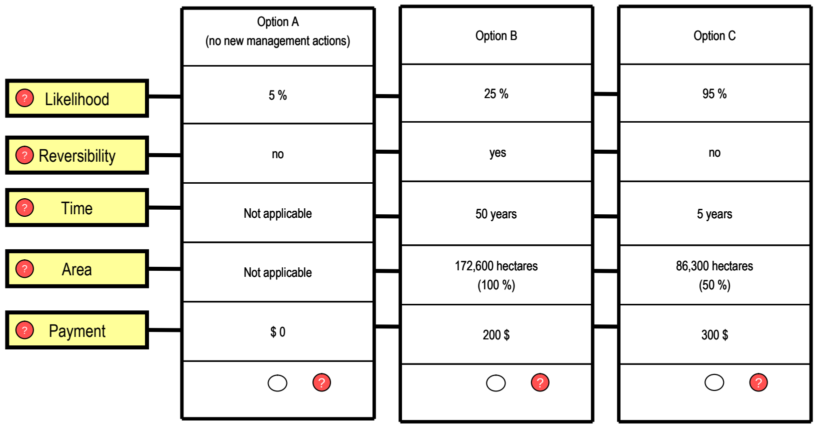


Table 1: Attributes and attribute levels

Attribute	Attribute level	Coding
Cost One-off household payment	$0 $50 $100 $200 $300	numerical
Likelihood Probability of an ecosystem to remaining in its current stable state (percentage)	5% 25% 50% 75% 95%	numerical
Reversibility Reversibility of an ecosystem shift (yes/no)	yes (1) no (-1)	effects coded
Time Time period over which there is an increased probability that the ecosystem remains in its current stable state (years)	5 years 10 years 20 years 50 years	numerical
Area Area over which there is an increased probability that the ecosystem remains in its current stable state (hectares)	43,150 ha (25%) 86,300 ha (50%) 129,450 ha (75%) 172,600 ha (100%)	numerical

The concept of ecosystem resilience was explained to respondents in the survey. Focus groups and the pilot survey were used extensively to balance the language between simplicity and scientific precision. An example choice set was included into the survey to support respondents' understanding of the concept and the choice task. Additionally, each choice set contained help functions allowing respondents to retain the definition of each variable and each option at any time during the choice task.

A Bayesian D-efficient design (Bliemer *et al.* 2008) was used to generate the choice sets[7]. The design consisted of 20 choice sets that were divided into four blocks of five choice sets each. Respondents were randomly assigned to one of the four choice blocks answering five choice questions each[8]. The order of the choice questions was randomized to avoid any order effects.

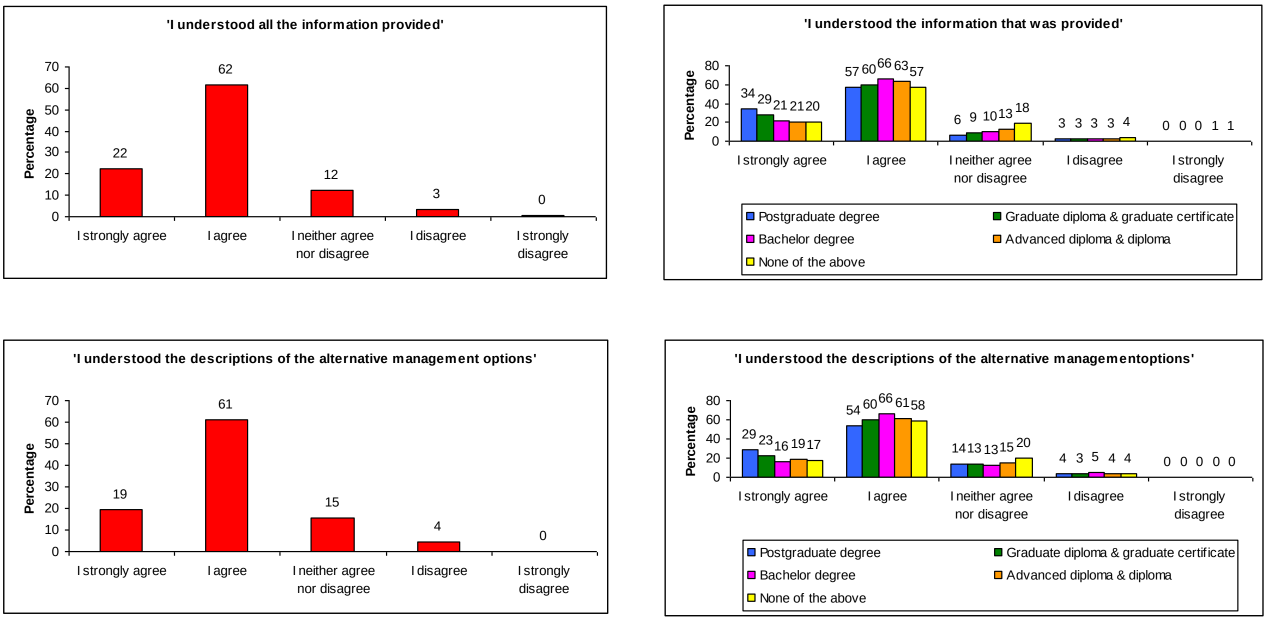
5 Results

Follow-up question were included in the questionnaire to explore whether the concept of ecosystem resilience was communicated successfully to respondents. The results, illustrated in Figure 2, show that about 84% of the respondents stated they understood all the information that was provided and about 80% stated that they understood the descriptions of the alternative management options. These results indicate that the majority of respondents thought they understood the concept of ecosystem resilience as described in the survey. The results show that respondents with higher levels of education believed they had a better understanding of the questionnaire than those with a lower level of education. Of course, follow-up questions are subjective. That is, it remains unclear to what extent respondents' perceptions of their understanding and their actual understanding coincide.

[7] The Bayesian D-efficient design (100 Halton draws) was developed based on the calculation of the Db-error of randomly selected designs (10,000 iterations).

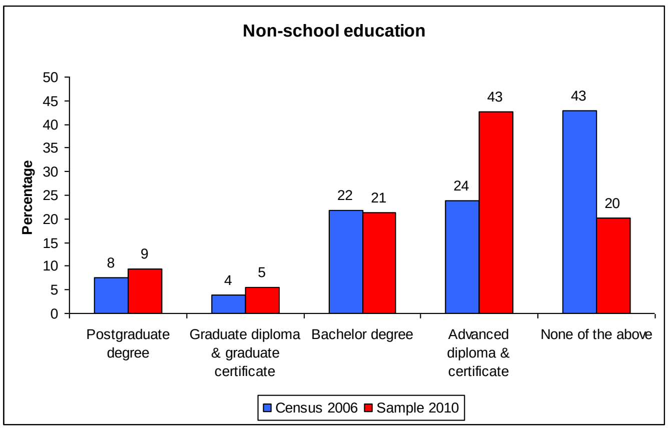
[8] Respondents were not allowed to click backwards.

Figure 2: Follow-up questions



To investigate whether the complexity of the concept of ecosystem resilience resulted in sample selection we compared the sample with census data provided by the Australian Bureau of Statistics (2006) with respect to non-school education levels (see Figure 3). We find statistically significantly different proportions across the two data sets (at the one percent level), mainly driven by the categories ‘Advanced Diploma and Certificate’ and ‘No Non-School Education’. The sample over-represents the former and under-represents the latter category.

Figure 3: Comparison of sample data with Census data 2006



A panel mixed logit model was estimated in WTP space to derive implicit prices for the determinants of ecosystem resilience. The results are reported in Table 2. Both the chi-statistic and the McFadden pseudo $\rho^2_{adj.}$ indicate a reasonable model fit. The estimates for all four implicit prices are statistically significantly different from zero at the one percent level and positive suggesting that respondents have a positive implicit price for attributes used to describe improved ecosystem resilience. This supports the findings of the follow-up questions: respondents were capable of understanding the concept of ecosystem resilience and were able to express their preferences in a conceptually consistent manner. Furthermore, the diagonal elements of the Cholesky matrix are statistically significantly different from zero at the one percent level for *likelihood* and *reversibility*, and at the ten percent level for *time.* This indicates that the implicit prices for these attributes are heterogeneous across respondents, whereas the implicit price for *area* is not. The parameter estimates for income[9] and age[10] are statistically significantly different from zero at the one percent and five percent level, respectively, and have the expected signs. Older respondents and respondents with higher income have higher willingness to pay than on average. The two variables representing non-school education levels are also statistically significantly different from zero at the one percent level and have the expected signs indicating that respondents with a higher non-school education level have a higher willingness to pay than on average[11]. The parameter estimate for gender[12] is not statistically significantly different from zero. The estimates of the implicit prices were used to calculate compensating surplus for alternative levels of marginal

[9] Household income; coded numerically

[10] Coded numerically

[11] Effects coded: education_1 (1,0); education_2 (0,1); education_3 (-1,-1)

[12] Effects coded: 1 female; -1 male

improvements in ecosystem resilience. Respondents are, on average, willing to pay $854.91 to improve ecosystem resilience to the maximum level (Table 3).

Table 2: Results of the panel mixed logit model estimated in WTP space

Variable	Coefficient[a]		Standard error
Nonrandom parameters			
constant	13.2*	(0.07)	7.17
age	0.28**	(0.04)	0.14
income	1.12***	(0.01)	0.41
gender	2.54	(0.12)	1.64
education_1	5.86***	(0.01)	2.31
education_2	-10.6***	(0.00)	2.47
Random parameters			
cost (n)	-2.75***	(0.00)	0.05
likelihood (n)	4.53***[b]	(0.00)	0.24
reversibility (n)	5.69***	(0.00)	0.47
area (n)	1.87***	(0.00)	0.31
time (n)	1.39***	(0.00)	0.09
Diagonal values in Cholesky matrix			
cost (n)	-0.78***	(0.00)	0.06
likelihood (n)	5.46***[b]	(0.00)	0.32
reversibility (n)	-6.18***	(0.00)	0.91
area (n)	0.07	(0.91)	0.64
time (n)	0.31*	(0.07)	0.18
Off-diagonal values in Cholesky matrix			
likelihood - reversibility	11.5***	(0.00)	0.83
time - likelihood	7.02***	(0.00)	0.55
time - reversibility	-3.31***	(0.00)	0.49
area - likelihood	1.18***	(0.00)	0.12
time - area	0.42***	(0.00)	0.14
Model statistics			
N (observations)	9035		
LL_{β}	-6582.728		
$\chi^2_{,22}$	6686.469		
McFadden pseudo ρ^2 adj.	0.335		

[a] ***=significant at 1% level, **=significant at 5% level, *=significant at 10% level; p-values in parentheses;
[b] The variable reversibility was divided by the factor 10 to support the model estimation.

Table 3: Compensating surplus for marginal improvement in ecosystem resilience

Attribute	Mean WTP	95% confidence interval
Likelihood	$4.53/ %	$4.06 - $5.00
Reversibility	$56.90/ yes	$47.69 -$66.11
Time	$1.87/ year	$1.26 - $2.48
Area	$1.39/ 1000 ha	$1.21 - $1.57

Compensating surplus: $854.91 ($732.62 - $977.20)

Likelihood	5%	95%
Reversibility	irreversible	reversible
Time	-	50 years
Area	-	172,600 ha

6 Conclusion

This paper investigated peoples' values for ecosystem resilience using discrete choice experiments. We explored sampled respondents' understanding of the concept of ecosystem resilience and estimated implicit prices for attributes that describe ecosystem resilience. Our results suggest that the questionnaire successfully communicated the complex concept of ecosystem resilience to the majority of respondents. However, a comparison of the sample with the census data from 2006 shows that the sample is biased towards higher educated respondents. That is, the complexity of the topic may have introduced sample selection bias. Since our results additionally indicate that the level of non-school education influences willingness to pay, the sample selection bias may have lead to an overestimation of compensating surplus for an improvement in ecosystem resilience.

We find evidence that implicit prices for the attributes describing improved ecosystem resilience are positive and statistically significantly different from zero. Compensating surpluses for improvements in ecosystem resilience of the Border Ranges rainforests are non-zero. We also find that implicit prices for likelihood, reversibility and time vary across respondents. Consequently, our results suggest that compensating surplus for marginal improvements in ecosystem resilience is heterogeneous across respondents.

In this study we explored ecosystem resilience for only one particular ecosystem type. It remains unclear whether the values for ecosystem resilience vary across ecosystem types. Furthermore, our scenario suggested a relatively high probability for an ecosystem change in the 'no new management' option. Whether the distance to a tipping point influences values remains unknown. More research is needed to investigate these open questions.

Additionally, precise scientific predictions of alternative scenarios are not yet readily available and are limited to a few case studies. Even though progress is being made in measuring ecosystem resilience it remains a challenge. However, examining preferences for ecosystem resilience based on potential scenarios will provide 'generic' values that can be adjusted once scientific predictions become more precise.

Ecosystem resilience looks to be a driver of biodiversity values. Values for ecosystem resilience are likely to be useful for prioritizing the different threats to biodiversity for management and investment purposes.

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