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Abstract

The valuation of complex environmental goods represents a considerable challenge for conventional non-market valuation techniques. The use of life satisfaction (or happiness) data has recently emerged as a new means of placing monetary values on non-market goods and services. This approach offers several advantages over more conventional techniques. This paper uses data from the Household, Income and Labour Dynamics in Australia (HILDA) survey along with Geographic Information Systems data to value ecosystem diversity in South East Queensland, Australia. It is found that, on average, a respondent has an implicit willingness-to-pay of approximately AUD$11 000 in household income per annum to obtain a one unit improvement in ecosystem diversity. This result confirms that the preservation, or improvement, of existing levels of ecosystem diversity is welfare enhancing. To our knowledge, this is the first paper to value ecosystem diversity using the life satisfaction approach.

Keywords: Biodiversity; Ecosystem Diversity; Household, Income and Labour Dynamics in Australia (HILDA); Life Satisfaction; Non-market Valuation.

JEL Codes: C21; I31; Q51; R10

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1. Introduction

It is well recognised that biodiversity provides many direct and indirect benefits to humans. It is equally well recognised that human activity has contributed to unprecedented rates of biodiversity loss (cf. Secretariat of the Convention on Biological Diversity, 2010). Moreover, projections show continuing and, in many cases, accelerating species extinctions, loss of natural habitat and changes in the distribution and abundance of species over the remainder of the 21st Century (Leadley et al., 2010). Ensuring biodiversity is more accurately valued may go some way to halt this decline. As noted in the most recent Global Biodiversity Outlook:

> *Perverse subsidies and the lack of economic value attached to the huge benefits provided by ecosystems have contributed to the loss of biodiversity. Through regulation and other measures, markets can and must be harnessed to create incentives to safeguard and strengthen, rather than to deplete, our natural infrastructure.*
>
> (Secretariat of the Convention on Biological Diversity, 2010 p.12)

At a microeconomic level, valuation enables the benefit of biodiversity preservation (or alternatively, the cost of biodiversity depletion) to be included within benefit-cost analyses; at a macroeconomic level, valuation allows national accounts to be augmented to better reflect the impact of economic activity on a society's natural capital. Values may also be used to assess damages for litigation purposes.

While the motivation for valuing biodiversity is clear, there remains no established framework for doing so (Czajkowski et al., 2009; Nijkamp et al., 2008). On top of the usual difficulties associated with trying to place monetary values on non-market environmental goods and services (cf. Freeman, 2003), two additional challenges are apparent. First, it is not immediately obvious which quantifiable indicator of biodiversity is best to use. Second, indicators preferred by ecologists are often not understood by the general public, from whom values must be elicited. That is, there is often a disconnect between the 'goods' demanded by the public and ecologists' understanding of what is important for ecosystem functioning (Spash, 2008).

Taking a relatively novel approach, this paper uses data on self-reported life satisfaction along with a spatially disaggregated Simpson's diversity index (Simpson, 1949) to place a monetary value on ecosystem diversity in South East Queensland (SEQ), Australia. In terms of addressing the first challenge, while the two terms are not synonymous, a considerable number of ecologists advocate the measure of biodiversity at the level of ecosystem diversity (Nunes and van den Bergh, 2001). In regards to the second challenge, as noted in Section 1.2, a key advantage of the life satisfaction approach is that it does not require respondents to have specific knowledge of the good in question, nor does it ask them to perform the unfamiliar task of placing a monetary value on a non-market good. The approach may therefore be ideally suited to the valuation of complex environmental goods. To our knowledge, this is the first attempt to use this approach to value ecosystem diversity.

The paper proceeds as follows: The remainder of this section briefly reviews relevant literature. Section 2 describes methodology and data. Section 3 presents model results. Section 4 discusses and concludes.

1.1 The biodiversity valuation literature

There are many studies that seek to value single or multiple species, with the focus often on charismatic species rather than those of ecological importance. A meta-analysis of single species studies is provided by Richardson and Loomis (2009). Similarly, a number of studies have sought to value ecosystem services, with a special issue of *Ecological Economics* devoted to this topic in 2000. Most of these studies, however, cannot truly be regarded as attempts to value biodiversity. In a critical review, Nunes and van den Bergh (2001) make clear the distinction between studies that value biological *diversity* and those that value biological *resources*. The authors conclude that while monetary value estimates give unequivocal support to the view that biodiversity has a significant positive social value, the failure of the empirical literature to apply economic valuation to the entire range of biodiversity benefits suggests that available valuation estimates should be regarded as providing, at best, lower bounds to the value of changes in biodiversity. This position is supported by Ressureicao et al. (2012), who note that the valuation literature continues to consider changes in individual components of biodiversity, rather than attempt to value biodiversity as a whole. A comparative study of the biodiversity valuation literature is provided by Nijkamp et al. (2008).

1.2 Valuing the environment using life satisfaction data

There is now a considerable body of literature on life satisfaction in economics (cf. Clark et al., 2008; Frey and Stutzer, 2002a, b; MacKerron, 2012) and a small body of literature suggesting that external influences, in particular natural environments, are key drivers of life satisfaction (cf. Brereton et al., 2008; Cunado and Perez de Gracia, 2012; Smyth et al., 2008). It is from this literature that the life satisfaction approach to non-market valuation has developed. Simply, this approach entails the inclusion of non-market goods as explanatory variables within micro-econometric functions of life satisfaction along with income and other covariates. The estimated coefficient for the non-market good yields first, a direct valuation in terms of life satisfaction, and second, when compared to the estimated coefficient for income, the implicit willingness-to-pay for the non-market good in monetary terms (Frey et al., 2010).

Applications of the life satisfaction approach to the valuation of environmental goods and services to date include, the valuation of air quality (cf. Cunado and Perez de

Gracia, 2012; Ferreira and Moro, 2010; Luechinger, 2009; MacKerron and Mourato, 2009; Welsch, 2002, 2006), airport noise (cf. van Praag and Baarsma, 2005), climate (cf. Ferreira and Moro, 2010; Frijters and van Praag, 1998; Maddison and Rehdanz, 2011), scenic amenity (cf. Ambrey and Fleming, 2011), floods (cf. Luechinger and Raschky, 2009) and drought (cf. Carroll et al., 2009). A review of many of these studies is provided by Welsh and Kuhling (2009).

The life satisfaction approach offers several advantages over more conventional non-market valuation techniques, particularly those found in the biodiversity valuation literature. For example, the approach does not ask individuals to directly value the non-market good in question, as is the case in contingent valuation. Nor does it ask individuals to make explicit tradeoffs between market and non-market goods, as is the case in choice modelling. Instead, individuals are asked to evaluate their general life satisfaction. This is perceived to be less cognitively demanding, as specific knowledge of the good in question is not required and respondents are not asked to perform the unfamiliar task of placing a monetary value on a non-market good. Further, the approach avoids the problem of lexicographic preferences, where respondents to contingent valuation or choice modelling questionnaires demonstrate an unwillingness to trade off the non-market good for income (Spash and Hanley, 1995). There is also no reason to expect strategic behaviour or social desirability bias in relation to the good being valued (Welsch and Kuhling, 2009).

The life satisfaction approach nonetheless has some potential limitations. Crucially, self-reported life satisfaction must be regarded as a good proxy for an individual's utility. Evidence in support of the use of this proxy is provided by Frey and Stutzer (2002b) and Krueger and Schkade (2008). Furthermore, in order to yield reliable non-market valuation estimates, self-reported life satisfaction measures must: (1) contain information on respondents' global evaluation of their life; (2) reflect not only stable inner states of respondents, but also current affects; (3) refer to respondents' present life; and (4) be comparable across groups of individuals under different circumstances (Luechinger and Raschky, 2009). Despite these conditions, there is growing evidence to support the suitability of individual's responses to life satisfaction questions for non-market valuation (cf. Frey et al., 2010).

In applying the life satisfaction approach there is another limitation to consider; the estimation of the income coefficient. There is now a large literature showing that individuals compare current income with past situations and/or the income of their peers. Therefore, both relative *and* absolute income matter (cf. Clark et al., 2008; Ferrer-i-Carbonell, 2005). As a result, when absolute income is included as an explanatory variable in life satisfaction regressions, small estimated income coefficients are common. This contributes to large marginal willingness-to-pay estimates (Luechinger, 2009).

It is also important to acknowledge that there is some debate in the literature about the nature of the relationship between the hedonic pricing and life satisfaction approaches to non-market valuation. Some authors take the view that the life satisfaction approach values only the residual benefits (or costs) of the non-market good not captured in housing or labour markets (cf. Luechinger, 2009; van Praag and Baarsma, 2005). More recently, Ferreira and Moro (2010) suggest that the relationship depends on whether the hedonic markets are in equilibrium or disequilibrium, as well as on the econometric specification of the life satisfaction function. If the assumption of equilibrium in the housing and labour markets hold, then no relationship should exist between the non-market good and life satisfaction, because housing costs and wages would fully adjust to compensate. If however a significant relationship is found, then residual benefits must remain.

2. Method and Data

The life satisfaction model takes the form of an indirect utility function for individual i in location k as follows:

$$U_{i,k} = \alpha + \beta \ln(y_{i,k}) + \gamma' x_{i,k} + \delta \ln(a_k) + \theta' b_{i,k} + \varepsilon_{i,k} \quad i = 1 \ldots I, k = 1 \ldots K \qquad (1)$$

Where $y_{i,k}$ is household income, $x_{i,k}$ is a vector of socio-economic and demographic characteristics including age, marital status, employment status, education and so forth, a_k is a spatially weighted average measure of ecosystem diversity for the collection district (CD)[2] in which the respondent resides and $b_{i,k}$ is a vector of spatial controls including administrative boundaries and measures of proximity to various amenities and disamenities (some of which vary at the individual level). In the micro-econometric life satisfaction function, the individual's true utility is unobservable; hence self-reported life satisfaction is used as a proxy.

Similar to the strategy employed by other authors (cf. Brereton et al., 2008; Smyth et al., 2008) an ordered probit model is estimated by maximum likelihood estimation. As we include explanatory variables at different spatial levels, standard errors are adjusted for clustering (cf. Moulton, 1990).

As shown by Ferreira and Moro (2010) and Welsch (2006), it is possible to estimate the willingness-to-pay (denoted WTP) for a marginal change in ecosystem diversity by taking the partial derivative of ecosystem diversity and the partial derivative of household income, as follows:

[2] The CD is the smallest spatial unit in the Australian Standard Geographical Classification Australian Bureau of Statistics, 2010. Australian Standard Geographical Classification, Catalogue No. 1216.0, Canberra..

$$WTP = \frac{\frac{\partial U}{\partial a_k}}{\frac{\partial U}{\partial y_{i,k}}} = \frac{\bar{y}\hat{\delta}}{\bar{a}\hat{\beta}} \quad (2)$$

Where $\bar{y}$ is the mean value of household income. If discrete changes are to be valued, the Hicksian welfare measures of compensating and equivalent surplus can be employed. In this case, the compensating surplus is the amount of household income an individual would need to receive (pay) following a deterioration (improvement) in the level of ecosystem diversity in his or her CD, in order to remain at his or her initial level of utility. Compensating surplus can be calculated as follows:

$$CS = -\exp\left[\overline{\ln(y)} + \frac{\hat{\delta}}{\hat{\beta}}(a^1 - a^2)\right] + \bar{y} \quad (3)$$

Where a^1 is the initial, and a^2 the new level of ecosystem diversity. Similarly, the equivalent surplus is the amount of household income an individual would need to receive or pay in order to obtain the level of utility following a change, *if the change did not take place*. Equivalent surplus can be calculated as follows:

$$ES = \exp\left[\overline{\ln(y)} + \frac{\hat{\delta}}{\hat{\beta}}(a^2 - a^1)\right] - \bar{y} \quad (4)$$

2.1 South East Queensland bioregion

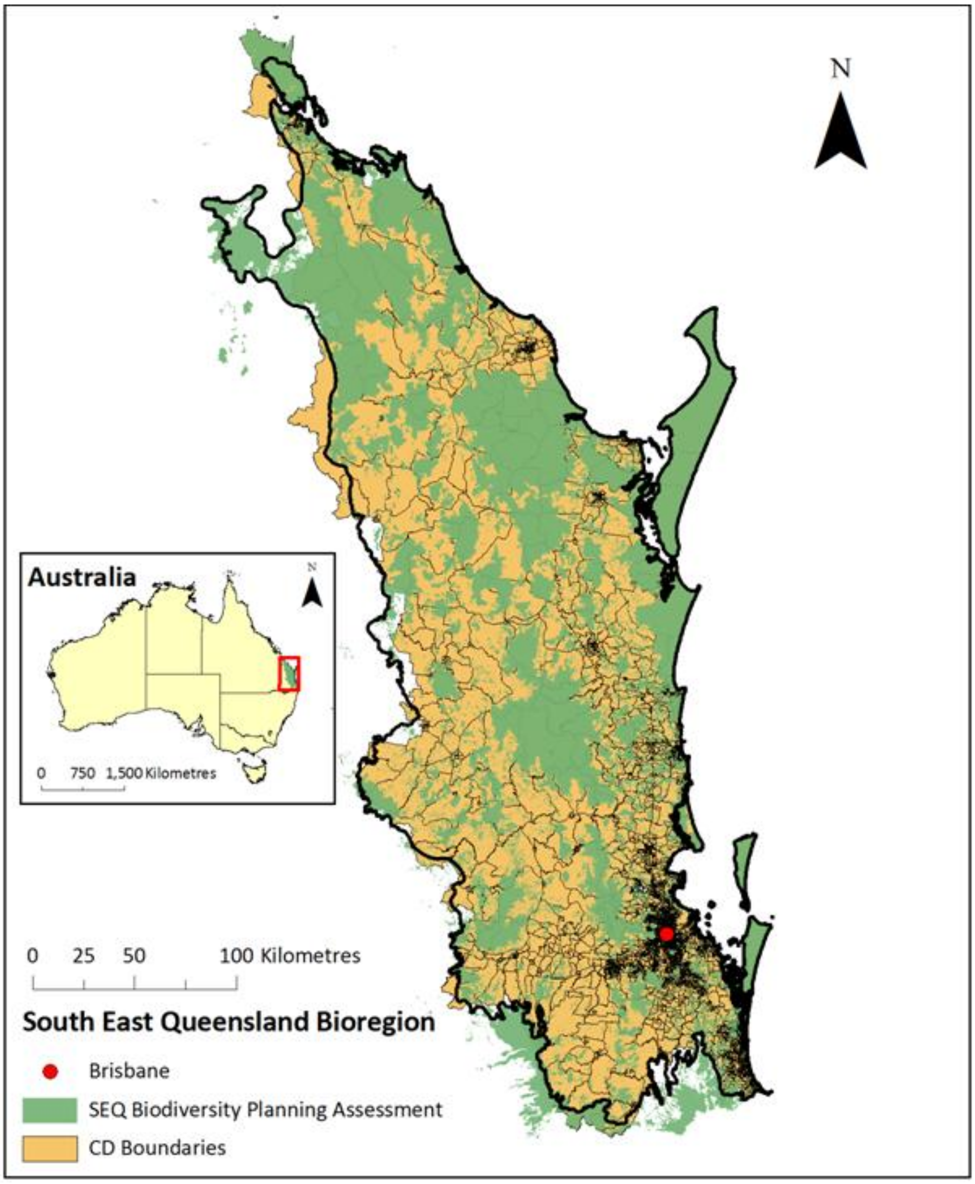
The study area, the SEQ *bioregion*,[3] covers an area of 59 403 km^2 (Fig. 1) and is one of eighty-five bioregions in Australia. The SEQ *region*, occupying the southern half of the SEQ bioregion, is the most densely populated part of Queensland, experiencing rapid population growth over the previous two decades. In 2007 Brisbane City, the principle urban centre of the SEQ region, was the second fastest growing urban centre in the developed world (Newman, 2007). Moreover, the resident population of the region is projected to increase by 44%, to 4.4 million, by 2031 (Office of Economic and Statistical Research, 2010).

Accompanying this significant population growth has been continued biodiversity loss as a result of native habitat degradation and fragmentation, competition from

[3] Bioregions are large, geographically distinct areas of land with common characteristics such as geology, landform patterns, climate, ecological features, and plant and animal communities Australian Government, 2011. Australia's bioregions. Available http://www.environment.gov.au/parks/nrs/science/bioregion-framework/index.html, accessed: 4 August..

introduced plant and animal species, and climate change. Peterson et al. (2007) take the view that the SEQ bioregion appears to be at a critical threshold, where increased development throughout the urban footprint is likely to lead to increasing loss and degradation of remaining ecosystems and their fauna. There is little doubt that biodiversity loss is a pertinent issue for the region.

Figure 1: SEQ Bioregion



Source: Queensland Environmental Protection Agency (2007)

2.2 Household, Income and Labour Dynamics in Australia

The measure of self-reported life satisfaction and the various socio-economic and demographic characteristics are obtained from Wave 5 (2005) of the Household, Income and Labour Dynamics in Australia (HILDA) survey.[4] First conducted in 2001, by international standards the HILDA survey is a relatively new nationally representative sample and owes much to other household panel studies conducted elsewhere in the world; particularly the German Socio-Economic Panel and the British Household Panel Survey. For a recent review of progress and future developments of the HILDA survey see Watson and Wooden (2010).

The life satisfaction variable is obtained from individuals' responses to the question: *'All things considered, how satisfied are you with your life?'* The life satisfaction variable is an ordinal variable, the individual choosing a number between 0 (totally dissatisfied with life) and 10 (totally satisfied with life).

Of particular importance to the valuation aspect of this paper is the definition of household income. Acknowledging the diminishing marginal utility of income, the income measure employed is the natural log of self-reported nominal disposable household income with imputed values for missing data.

In terms of model estimation, Ferrer-i-Carbonell and Frijters (2004) identified the treatment of time-invariant unobserved factors as critical to the validity of results. Specifically, the error term captures measurement errors as well as unobserved characteristics. Thus, results can be obscured by personality traits that aren't taken into account (Bertrand and Mullainathan, 2001). Extending the efforts of Shields et al. (2009) an attempt is made to capture the heterogeneity that arises from differences in personality through the inclusion of additional variables, namely: extraversion; agreeableness; conscientiousness; emotional stability; and openness to experience. These personality trait variables are commonly known as the 'Big Five' (Saucier, 1994). Social desirability bias is also controlled for by the inclusion of a variable indicating whether or not the individual was interviewed in the presence of another person.

2.3 Spatial data

Ecosystem diversity data is constructed via a Biodiversity Assessment and Mapping Methodology and provided, for each remnant unit[5] in the SEQ bioregion, by the Department of Environment and Resource Management (Queensland Environmental Protection Agency, 2007). The Methodology was developed in order to provide a consistent approach for assessing biodiversity values at the landscape scale in

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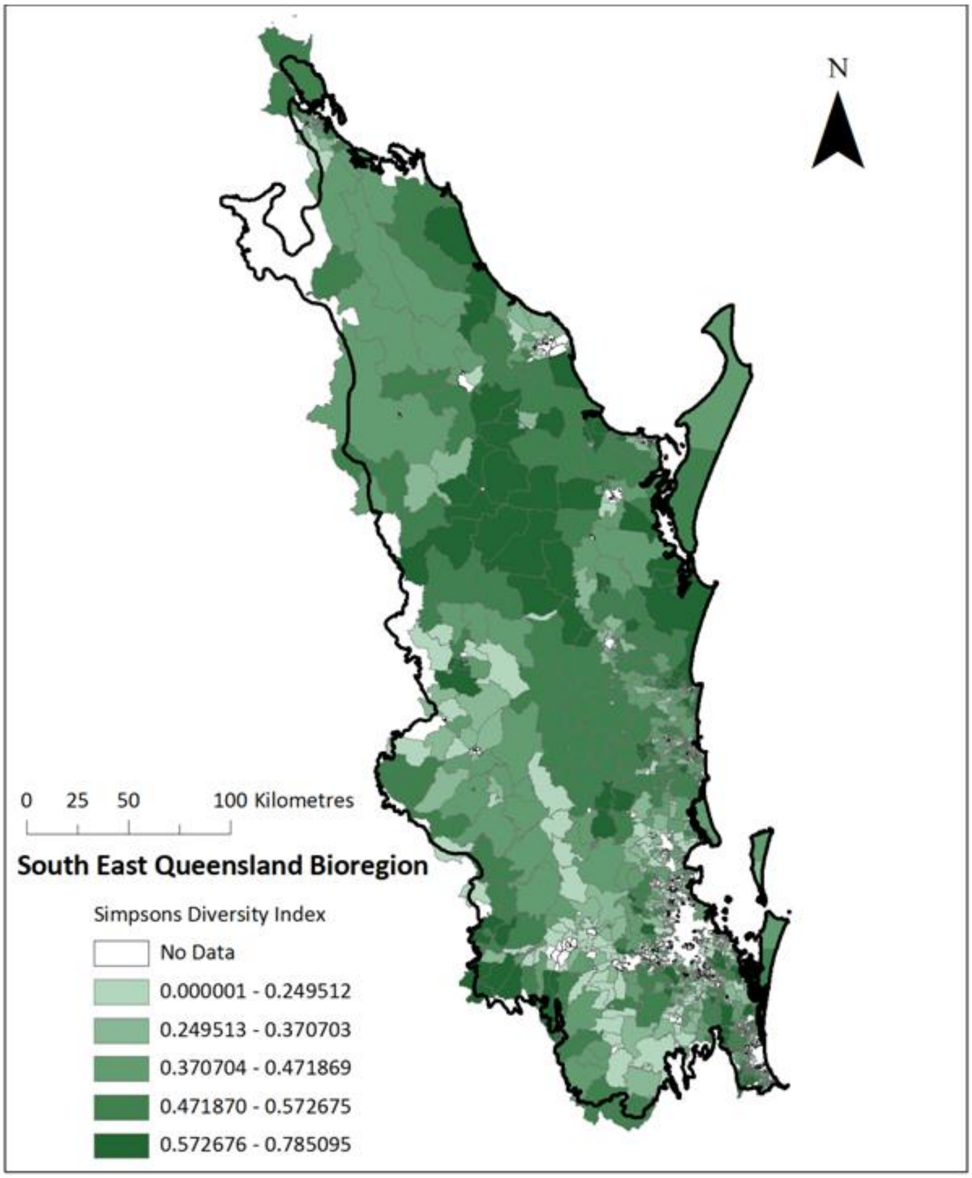
[4] Wave 5 is employed as it closely matches the date of collection of the spatial ecosystem diversity data. Further, Wave 5 includes a range of personality trait questions, thus allowing personality traits to be controlled for in model estimation.

[5] The remnant unit is the basic planning unit for assessing biodiversity significance. It is equivalent to a single polygon on a map approved by the Queensland Herbarium Queensland Environmental Protection Agency, 2002. Biodiversity Assessment and Planning Methodology. Biodiversity Planning Unit, Brisbane..

Queensland, using vegetation mapping data generated or approved by the Queensland Herbarium. It is used by the Department of Environment and Resource Management to generate Biodiversity Planning Assessments for the bioregions in eastern Queensland most under pressure from development (Queensland Environmental Protection Agency, 2002).

Within the Biodiversity Assessment and Mapping Methodology ecosystem diversity is measured via the Simpson's diversity index (Simpson, 1949). This index incorporates the ecosystem diversity concepts of 'richness' (number of different ecosystems) and 'evenness' (relative abundance), and ranges between zero and one, with high scores representing areas of high densities of regional ecosystems and ecotones (transitional areas between ecosystems). The index is then spatially weighted for each CD. The spatial variation of the Simpson's diversity index over the CDs in the study region is illustrated in Fig. 2.

Figure 2: Spatial variation of the Simpson's diversity index in SEQ



Source: Queensland Environmental Protection Agency (2007)

Like Naidoo and Adamowicz (2005) and Horne et al. (2005), who find non-linear effects for species diversity in their indirect utility function, we employ a natural log transformation of the Simpson's diversity index. This functional form captures, as with income, the diminishing marginal utility that might be expected *a priori* with additional increments of ecosystem diversity. A marginal change in ecosystem diversity is defined as a one per cent change in the likelihood that two randomly sampled regional ecosystems are different. A worked example of calculating the Simpson's diversity index is provided as an Appendix.

In creating the spatial control variables we follow Brereton et al. (2008) and assign individuals a value of one if the centroid or centre point of the CD the individual resides in falls within the straight line distance buffer from the nearest urban park, national park, coastline, river, lake, creek or brook and a zero otherwise. These variables allow us to abstract from the potential effects associated with an amenity or disamenity that might be highly correlated or otherwise confound the influence of ecosystem diversity on life satisfaction, such as the recreational benefits provided by being in close proximity to national parks. In using the CD, the lowest level of spatial disaggregation available,[6] to link ecosystem diversity to respondents, the measured ecosystem diversity is in close proximity to the individual's dwelling. For instance, for the 513 CDs in the sample, the mean size of the CD is 4.9323 km^2 yielding an approximate radius (if the CD is assumed to take roughly the shape of a circle) from the centre point of 1.2530 km.[7] All of the explanatory variables included within the model are summarised in Table 1.

Table 1: Model variables

Variable	**Definition**	**Mean (std. dev.)**	**% value 1 (DV)**
Age	Age of respondent in years	42.4479 (17.3290)	
Male	Respondent is male		46.3%
ATSI	Respondent is of Aboriginal and/or Torres Strait Islander origin		2.2%
Immigrant English	Respondent is born in a Main English Speaking country (Main English Speaking countries are: United Kingdom; New Zealand; Canada; USA; Ireland; and South Africa)		12.2%
Immigrant non-English	Respondent is not born in Australia or a Main English Speaking country		6.4%
Poor English	Respondent speaks English either not well or not at all		0.2%
Married	Respondent is legally married		49.1%
De facto	Respondent is in a de facto relationship		14.4%
Separated	Respondent is separated		3.0%
Divorced	Respondent is divorced		7.5%
Widow	Respondent is a widow		3.5%
Number of children	Number of respondent's own resident children	0.7074 (1.0794)	
Lone parent	Respondent is a lone parent		10.6%
Mild health condition	Respondent has a long-term health condition, that is a condition that has lasted or is likely to last for more than six months, and this condition does not limit the type or amount of work the respondent can do		9.6%
Moderate health condition	Respondent has a long-term health condition limiting the amount or type of work that the		15.9%

[6] Due to confidentiality issues, individual respondents' home addresses are not available.

[7] While ecosystem diversity may generate ecosystem services at a broader scale, we find no statistically significant relationship between life satisfaction and ecosystem diversity beyond the local area.

	respondent can do		
Severe health condition	Respondent has a long-term health condition and cannot work		0.6%
Year 12	Respondent's highest level of education is Year 12		2.2%
Certificate or diploma	Respondent's highest level of education is a certificate or diploma		31.0%
Bachelors degree or higher	Respondent's highest level of education is a Bachelors degree or higher		17.8%
Employed part-time	Respondent is employed and works less than 35 hours per week		21.3%
Unemployed	Respondent is not employed but is looking for work		3.2%
Non-participant	Respondent is a non-participant in the labour force, including retirees, those performing home duties, non-working students and individuals less than 15 years old at the end of the last financial year		30.4%
Self-employed	Respondent is self employed		7.1%
Household income (ln)	Natural log of disposable household income	10.7934 (0.6770)	
Hours worked	Number of hours worked per week by respondent	24.1937 (20.8174)	
Commute time	Number of hours spent travelling to and from paid employment per week by respondent	2.5744 (3.4192)	
Extraversion	Degree of extraversion (scale 1 to 7)	4.4391 (1.0560)	
Agreeableness	Degree of agreeableness (scale 1 to 7)	5.3263 (0.9668)	
Conscientiousness	Degree of conscientiousness (scale 1 to 7)	5.0883 (1.0602)	
Emotional stability	Degree of emotional stability (scale 1 to 7)	5.0734 (1.0918)	
Openness to experience	Degree of openness to experience (scale 1 to 7)	4.2409 (1.0331)	
Others present	Someone apart from the interviewer and the respondent was present during the interview		34.5%
Ecosystem diversity (ln)	Natural log of the spatially weighted Simpson's diversity index for the CD in which the respondent resides	1.3208 (1.7597)	
Population density	Number of individuals per square kilometre in the CD	1559.0090 (1305.6120)	
Inner	Respondent resides in inner regional Australia		32.4%
Outer	Respondent resides in outer regional Australia		1.5%
Remote	Respondent resides in remote Australia, very remote Australia or the respondent resides in a region considered migratory		1.1%
Proximity to urban park	Respondent resides within 3 km of an urban park		91.8%
	Respondent resides between 3 km-10 km of an urban park		6.7%
Proximity to national park	Respondent resides within 3 km of a national park		11.9%

	Respondent resides between 3 km and 5 km of a national park	11.8%
	Respondent resides between 5 km and 10 km of a national park	27.6%
Proximity to coastline	Respondent resides within 3 km of a coastline	23.7%
	Respondent resides between 3 km and 5 km of a coastline	6.7%
	Respondent resides between 5 km and 10 km of a coastline	17.0%
Proximity to river	Respondent resides within 3km of a river	34.4%
	Respondent resides between 3 km and 5 km of a river	23.0%
	Respondent resides between 5 km and 10 km of a river	23.7%
Proximity to lake	Respondent resides within 3 km of a lake	39.0%
	Respondent resides between 3 km and 5 km of a lake	17.4%
	Respondent resides between 5 km and 10 km of a lake	30.8%
Proximity to creek	Respondent resides within 3 km of a creek	74.2%
	Respondent resides between 3 km and 5 km of a creek	17.9%
	Respondent resides between 5 km and 10 km of a creek	7.5%
Proximity to brook	Respondent resides within 3 km of a brook	4.9%
	Respondent resides between 3 km and 5 km of a brook	1.7%
	Respondent resides between 5 km and 10 km of a brook	11.5%

Omitted cases are: Female; Not of indigenous origin; Country of birth Australia; Speaks English well or very well; Never married and not de facto; Not a lone parent; Does not have a long-term health condition; Year 11 or below; Not self-employed (employee, employee of own business, unpaid family worker); Employed working 35 hours or more per week; No others present during the interview or don't know – telephone interview; Major city, Proximity to urban park greater than 10 km; Proximity to national parks greater than 10 km; Proximity to coastline greater than 10 km; Proximity to river greater than 10 km; Proximity to lake greater than 10 km; Proximity to creek greater than 10 km; Proximity to brook greater than 10 km.

3. Results

The estimated results for Equation 1 are presented in Table 2. The explanatory power of the model, as measured by a pseudo R^2 of 0.1048, is comparable to other studies of this type (cf. Shields et al., 2009). In regards to socio-economic and demographic characteristics, the results largely support the existing literature and *a priori* expectations. That is, life satisfaction is U-shaped in age, reaching a minimum at the age of 41. As also reported by Shields et al. (2009), respondents of Aboriginal and/or Torres Strait Islander origin are found to be more satisfied with their lives than the general population. Respondents who self-report having poor English speaking skills are found to be less satisfied than those who speak English well or very well. In terms of marital status, only being separated is found to have a statistically significant negative effect on life satisfaction. Lone parents similarly report lower levels of life satisfaction. As is found by many authors (cf. Brereton et al., 2008; Shields et al., 2009) a larger number of resident children in a household lowers a respondent's life satisfaction.

Consistent with Shields et al. (2009), household income enhances a person's life satisfaction, whereas having a long-term health condition is associated with lower levels of life satisfaction. With regards to education, tertiary educated respondents are found to be less satisfied than those with all other education levels.

The use of personality trait controls increases the model's explanatory power by 24%. The results show that three of the Big Five personality trait variables are statistically significant at the one per cent level, with higher degrees of extraversion, agreeableness and emotional stability all associated with higher levels of life satisfaction. There is no evidence of social desirability bias, with others being present during the interview having no significant effect on self-reported life satisfaction.

Of particular importance to this study, ecosystem diversity, as measured by the Simpson's diversity index described above, is found to have a positive and significant (at the 5% level) effect on life satisfaction, with an estimated coefficient of 0.0562. In regards to the spatial control variables, living within five and ten kilometres of a national park has a positive influence on life satisfaction, as does living within close proximity of a creek. However, living within close proximity of a river has a negative effect. No other spatial control variables had a significant impact on life satisfaction.

Table 2: Ordered probit model results

Variable name	**Estimate** (standard error)	**Variable name**	**Estimate** (standard error)
Age	-0.0419*** (0.0104)	Conscientiousness	0.0006 (0.0312)
Age squared	0.0005*** (0.0001)	Emotional stability	0.1634*** (0.0325)
Male	0.0647 (0.0661)	Openness to experience	-0.0181 (0.0375)
ATSI	0.5893** (0.2345)	Others present	-0.0352 (0.0668)
Immigrant English	-0.1111 (0.0904)	Ecosystem diversity (ln)	0.0562** (0.0265)
Immigrant non-English	-0.0717 (0.1207)	Population density	-0.0000 (0.0000)
Poor English	-0.8530* (0.4470)	Inner	-0.0576 (0.2272)
Married	0.1404 (0.1206)	Outer	-0.4866 (0.8381)
De facto	0.0672 (0.1157)	Remote	0.5117 (0.4511)
Separated	-0.7194***	Proximity to urban park	-1.0567

	(0.2007)	($b_k \leq 3$ km)	(0.6598)
Divorced	0.0483	Proximity to urban park	-0.7603
	(0.1402)	($3 < b_k \leq 10$ km)	(0.6807)
Widow	0.0331	Proximity to national park	0.2639
	(0.2299)	($b_k \leq 3$ km)	(0.2032)
Number of children	-0.0893**	Proximity to national park	-0.0134
	(0.0345)	($3 < b_k \leq 5$ km)	(0.1582)
Lone parent	-0.2225*	Proximity to national park	0.2438**
	(0.1314)	($5 < b_k \leq 10$ km)	(0.1169)
Mild health condition	-0.2424**	Proximity to coastline	-0.0525
	(0.1048)	($b_k \leq 3$ km)	(0.1469)
Moderate health condition	-0.3904***	Proximity to coastline	-0.0375
	(0.0928)	($3 < b_k \leq 5$ km)	(0.1916)
Severe health condition	-1.4984***	Proximity to coastline	-0.1364
	(0.4841)	($5 < b_k \leq 10$ km)	(0.1358)
Year 12	0.2828	Proximity to river	-0.4476**
	(0.1879)	($b_k \leq 3$ km)	(0.1882)
Certificate or diploma	-0.0662	Proximity to river	-0.4325**
	(0.0629)	($3 < b_k \leq 5$ km)	(0.1676)
Bachelors degree or higher	-0.1747**	Proximity to river	-0.5499***
	(0.0852)	($5 < b_k \leq 10$ km)	(0.1606)
Employed part-time	-0.0061	Proximity to lake	-0.1049
	(0.1109)	($b_k \leq 3$ km)	(0.1837)
Unemployed	-0.02289	Proximity to lake	-0.0054
	(0.2342)	($3 < b_k \leq 5$ km)	(0.1851)
Non-participant	0.0890	Proximity to lake	0.0525
	(0.2027)	($5 < b_k \leq 10$ km)	(0.1498)
Self-employed	0.1001	Proximity to creek	0.7135**
	(0.1103)	($b_k \leq 3$ km)	(0.3349)
Household income (ln)	0.1937***	Proximity to creek	0.5022
	(0.0521)	($3 < b_k \leq 5$ km)	(0.3487)
Hours worked	-0.0066	Proximity to creek	0.6502*
	(0.0041)	($5 < b_k \leq 10$ km)	(0.3661)
Commute time	0.0052	Proximity to brook	-0.2216
	(0.0093)	($b_k \leq 3$ km)	(0.1880)
Extraversion	0.1003***	Proximity to brook	-0.1358
	(0.0326)	($3 < b_k \leq 5$ km)	(0.2211)
Agreeableness	0.2051***	Proximity to brook	-0.0531
	(0.0399)	($5 < b_k \leq 10$ km)	(0.1480)
Summary statistics			
Number of observations	1715		
Likelihood ratio	-2516.2956		
Pseudo R^2	0.1048		

*** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

Omitted cases are: Female; Not of indigenous origin; Country of birth Australia; Speaks English well or very well; Never married and not de facto; Not a lone parent; Does not have a long-term health condition; Year 11 or below; Not self-employed (employee, employee of own business, unpaid family worker); Employed working 35 hours or more per week; No others present during the interview or don't know – telephone interview; Major city, Proximity to urban park greater than 10 km; Proximity to national parks greater than 10 km; Proximity to coastline greater than 10 km; Proximity to river greater than 10 km; Proximity to lake greater than 10 km; Proximity to creek greater than 10 km; Proximity to brook greater than 10 km.

Following the procedure described in Equation 2, the average implicit willingness-to-pay in terms of annual household income, for a one-unit improvement in ecosystem diversity, is $10 696.87.[8] Given, on average, there are 2.5 people living in each household in the sample this implies a per-capita willingness-to-pay of approximately $4300.

Similarly, a one standard deviation (1.7597) improvement in ecosystem diversity from the mean yields a compensating surplus of $15 935.12, thus suggesting, following such an improvement, an individual is able to sacrifice approximately $16 000 in annual household income and remain at his or her initial level of utility. The comparable equivalent surplus estimate is $22 279.82, suggesting an individual would require an increase in annual household income of approximately $22 000 for such an improvement *not to occur*.

4. Discussion

The rapid decline in biodiversity at a local and global level, coupled with projections of further future declines, indicates that better appreciating the welfare implications of declining biodiversity is of great importance. Unfortunately, conventional non-market valuation techniques struggle to accurately value complex environmental goods. The objective of this paper is to investigate and quantify in monetary terms the welfare effects of ecosystem diversity on life satisfaction in SEQ. In so doing, the paper employs a unique tool to infer values for ecosystem diversity, contributing to the existing biodiversity valuation literature as well as to the small, but growing, body of literature employing the life satisfaction approach to value environmental goods and services.

We find that increases in ecosystem diversity have a positive and economically significant effect on life satisfaction, and that on average an individual has an implicit willingness-to-pay of approximately $11 000 in annual household income for a one-unit improvement in ecosystem diversity in their local area, measured in terms of the Simpson's diversity index. While it is difficult to compare with existing studies employing more conventional non-market valuation techniques, it is reasonable to conclude that this estimate is at the upper end of valuations found in the literature. This may be due to biases inherent within the life satisfaction approach, or alternatively, may be a reflection of the fact that conventional techniques generally fail to value all of the benefits of biodiversity. Nevertheless, these estimates indicate that there are significant life satisfaction impacts of increased ecosystem diversity and that the preservation, or improvement, of existing levels of ecosystem diversity is welfare enhancing. The challenge for policy makers is to adequately manage the

[8] All figures are in AUD. As at 12 June 2012: 1 AUD = 0.79 EUR; 1 AUD = 0.99 USD.

pressures of projected population and economic growth in rapidly growing regions such as SEQ.

While not the main thrust of this investigation, from a theoretical perspective these value estimates point towards a substantial residual shadow value associated with ecosystem diversity that is not captured in housing costs or wages. Consistent with earlier life satisfaction valuation literature (cf. Luechinger, 2009; van Praag and Baarsma, 2005), this finding challenges the validity of the assumption of equilibrium in housing and wage markets, which underpins many models that rely on choice. In this context, the life satisfaction approach may serve as a useful complement to the hedonic method when attempting to value non-market goods.

As a final note, it should be acknowledged that implicit in the economic valuation of ecosystem diversity is the assumption that ecosystem diversity is substitutable. That is, at the margin, levels of ecosystem diversity can be traded for other goods and services. Given the irreplaceable nature of many biological assets and the limitations of current knowledge, a cautious approach is advocated when weighing up the relative costs and benefits of projects, policies or programs that may lead to further biodiversity decline.

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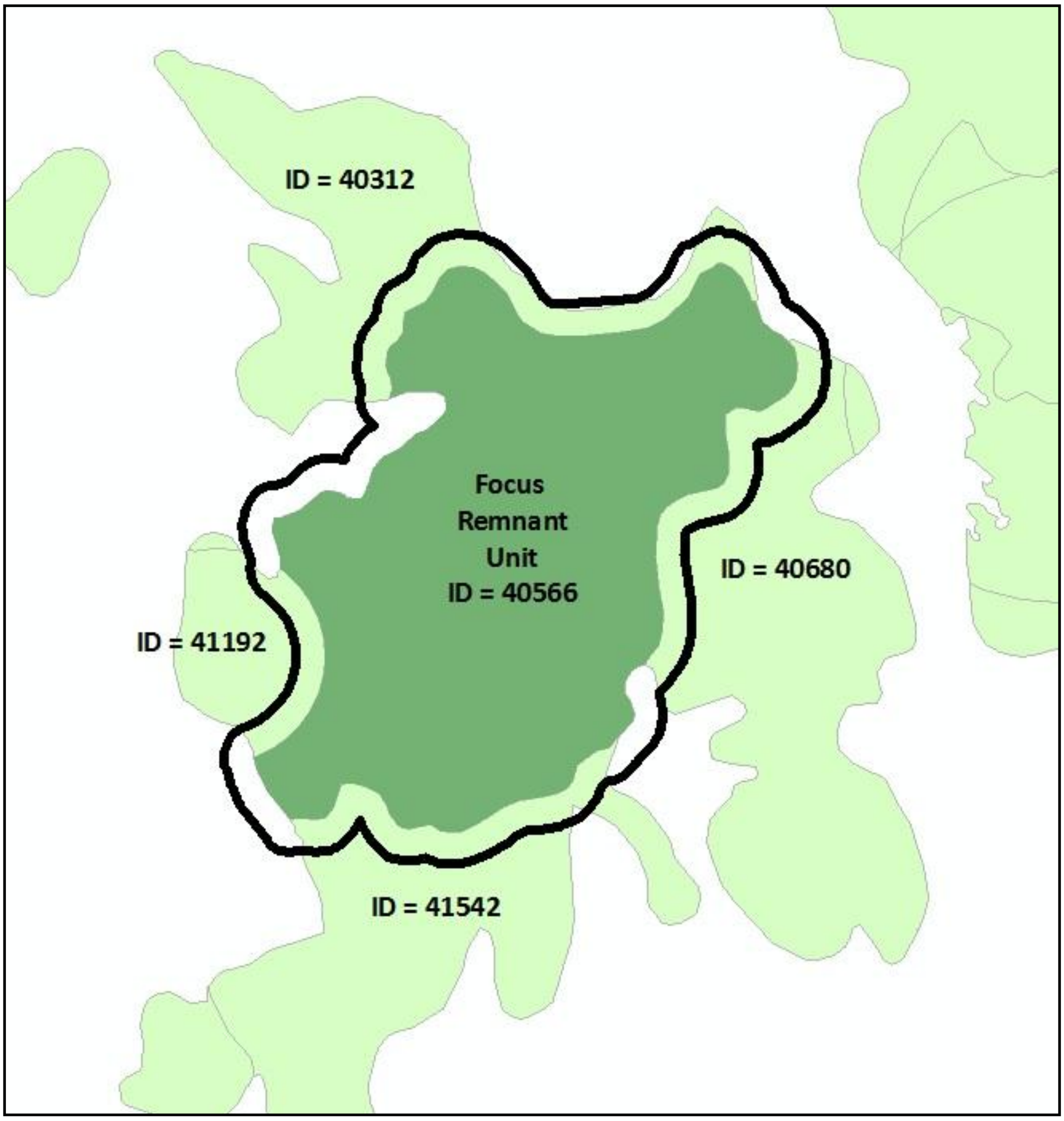
Appendix: Calculation of the Simpson's diversity index

This Appendix illustrates the calculation of the Simpson's diversity index for remnant unit No. 40566. Note that remnant units may contain one or more regional ecosystem. To measure the Simpson's diversity index, a buffer is placed around the focus remnant unit reflecting its shape. The width of the buffer is derived using the modal area of all remnant units within the bioregion (rounded to the nearest 50 metres). The index for the focus remnant unit is calculated within the total buffered area (Queensland Environmental Protection Agency, 2002). Fig. A1 below shows the remnant units captured in a buffer around remnant unit 40566. The areas in white illustrate landscape that has been cleared of vegetation.

Figure A 1: Remnant unit 40566 and buffer



Source: Queensland Environmental Protection Agency (2002)

To calculate the Simpson's diversity index, as shown in Equation A1, you need the number of regional ecosystems in the buffered region (*m*) and the squared proportional area (P_i^2) of each regional ecosystem.

$$SDI = 1 - \sum_{i=1}^{m} P_i^2 \qquad \text{(A1)}$$

Table A1 below illustrates the composition of the focus remnant unit and those remnant units that make up the buffer. In this instance, each remnant unit contains at least two regional ecosystems. Each regional ecosystem is identified by three numbers. For example, with respect to the regional ecosystem identified by 12.12.18, the first number indicates the bioregion the regional ecosystem belongs to, the second number distinguishes the land zone (a simplified geology/substrate landform classification) of the regional ecosystem, and the third number denotes the different vegetation type unique to the regional ecosystem system. It can be observed that the focus remnant unit contains two different regional ecosystems: 12.12.18 (65% of the total area of the remnant unit); and 12.12.13 (35% of the total area). Further detail on the regional ecosystem classification framework is provided by the Queensland Environmental Protection Agency (2002). Based on the information presented in Table A1, Table A2 outlines the calculation of the index for the focus remnant unit (40566). Thus, from Equation A1, the Simpson's diversity index for remnant unit 40566 is 1 - 0.3836 = 0.6164.

To help illustrate alternative levels of ecosystem diversity, Fig. A2 depicts the proportion of particular regional ecosystems in hypothetical areas with Simpson's diversity index scores of 0.50 and 0.75.

Table A 1: Remnant unit composition

Remnant unit ID	Total remnant area (hectares)	Regional ecosystem	Percentage of regional ecosystem within remnant unit	Regional ecosystem (hectares)
40566	1509.6494			
(focus unit)		12.12.18	65%	981.2721
		12.12.13	35%	528.3773
40312	131.4257			
		12.12.8	70%	91.9980
		12.12.7	20%	26.2851
		12.12.5	10%	13.1426
40680	110.6867			
		12.12.8	70%	77.4807
		12.12.7	20%	22.1373
		12.12.5	10%	11.0687
41192	54.9167			
		12.12.18	65%	35.6958
		12.12.13	35%	19.2208
41542	102.6260			
		12.12.8	70%	71.8382
		12.12.7	20%	20.5252
		12.12.5	10%	10.2626

Source: Queensland Environmental Protection Agency (2002)

Table A 2: Regional ecosystems and percentage of area

Regional ecosystem	Regional ecosystem as a proportion of the total area of regional ecosystems	p_i^2
12.12.8	0.1264	0.0160
12.12.7	0.0361	0.0013
12.12.5	0.0181	0.0003
12.12.18	0.5326	0.2837
12.12.13	0.2868	0.0823
Total	1.0000	0.3836

Source: Queensland Environmental Protection Agency (2002)

Figure A 2: Remnant unit composition (Simpsons's dviersity indec scores 0.50 and 0.75)