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Jarvis, Diane, Stoeckl, Natalie, and Liu, Hong-Bo (2017) ***New methods for valuing, and for identifying spatial variations, in cultural services: a case study of the Great Barrier Reef*****. Ecosystem Services, 24 pp. 58-67.**

Please refer to the original source for the final version of this work:

http://dx.doi.org/10.1016/j.ecoser.2017.02.012

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New methods for valuing, and for identifying spatial variations, in cultural services: A case study of the Great Barrier Reef

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Abstract

Estimating values for ecosystem services (ES) can contribute to the decision making process, reducing the risk that ES benefits are overlooked. For ES with no (direct or indirect) links to markets, valuation is a non-trivial exercise. Traditional methods require the use of hypothetical markets; the life satisfaction (LS) approach does not. LS has previously been used to estimate the value of regulating ES, but to the best of our knowledge has never been used to estimate the value of Cultural services (CS).

We examine the relationship between LS and a subset of CS provided by the Great Barrier Reef (GBR), (the non-use CS), using geographically weighted regression to investigate spatial variations in value. After controlling for other factors, we find income is more important to LS in the south than the north; the opposite is true for non-use CS.

The coefficients are used to estimate the amount of income required to keep overall LS constant, should the non-use CS of the GBR not be preserved, estimated at $8.7bn annually. We acknowledge the imperfections of our work, noting the need for research on better CS measures, but feel that the general approach may add another useful tool to the valuation toolbox.

Highlights

- Focuses on the value of ecosystem services provided by the Great Barrier Reef (GBR)
- Uses life satisfaction (LS) approach to estimate cultural ecosystem services values
- Uses geographically weighted regression for spatial analysis
- Finds income (cultural services) more important to LS in the south (north)
- Estimates the GBR's cultural ecosystem services value at approx. $8.7 bn per annum

Keywords

Cultural services; Non-market valuation; Geographically weighted regression; Life satisfaction; Spatial analysis of life satisfaction; Great Barrier Reef.

1 Introduction

Ecosystems provide mankind with an extensive range of goods and services that are critical to human welfare (Costanza et al., 1997; Daily et al., 2000). Valuation of ecosystem services (ES) is a useful tool available to decision makers tasked with managing resources (Daily et al., 2000). Monetising ES can provide a range of benefits that can help inform resource allocation decisions, including highlighting the appropriate weighting of vital services (Costanza et al., 1997), raising awareness about the importance of ES (de Groot et al., 2012), and making explicit the costs of ES degradation (Pascual et al., 2010).

Valuation has been criticised for not only failing to help conserve many of the world's ES, but by assisting the commodification process, facilitating their loss or degradation, (Gómez-Baggethun, de Groot, Lomas, & Montes, 2010; Gómez-Baggethun & Ruiz-Pérez, 2011). However, 'valuing ES is not identical to commodifying them for trade in private markets' (Costanza, 2006, p. 749), and need not lead to commodification (Gómez-Baggethun & Ruiz-Pérez, 2011). Indeed, the diverse nature of ES suggests that whilst some services may be susceptible to commodification, the complex overlapping and entangled benefits provided by many ES make it difficult to either monetise a single particular ES (Stoeckl, Farr, Larson, et al., 2014) or to separate a single function into a discrete commodifiable unit (Gómez-Baggethun & Ruiz-Pérez, 2011).

Some ES are easier to value than others, with cultural services being particularly difficult. Cultural services (CS) are the "nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences" (Millennium Ecosystem Assessment, 2005, p. 40) and include "…existence and bequest constructs that may arise from people's beliefs or understandings" (Haines-Young & Potschin, 2013, p. 18). CS have been described as comprising aesthetic information, opportunities for recreation and tourism, inspiration for culture, art and design, spiritual experience, and information for cognitive development (de Groot et al., 2010), or more succinctly, as encompassing cultural heritage, recreation and tourism, and aesthetic values (Pascual et al., 2010). Recreation and tourism aside, many other CS provide the type of benefits that people would assign what economists term non-use values (Krutilla, 1967; Weisbrod, 1964). Thus, CS essentially provide a hybrid of use and non-use benefits, each of which contribute to the overall value (use and non-use) assigned to the CS (Braat & de Groot, 2012; Pascual et al., 2010). A core problem of this being that the values assigned to the non-use CS are not traceable through well-functioning markets, or indeed through any market at all (Costanza et al., 1997).

Omitting non-use values of CS from valuation estimates risks excluding that which people may care about most (Carson, Flores, & Meade, 2001). Traditional non-market valuation approaches that have been explicitly developed to measure non-use values (such as contingent valuation, choice modelling) assume that utility is cardinally unobservable (Gowdy, 2005), requiring researchers to work with indirect utility functions derived from hypothetical markets. However, an emerging body of research has established that measures of life satisfaction (LS) or subjective well-being can serve as a proxy for utility (Kristoffersen, 2010) at both the microeconomic (Ferreira & Moro, 2010), and macroeconomic (Engelbrecht, 2009) level. Simplistically, LS researchers ask questions, such as "how satisfied are you with your life as a whole?", and responses are then regressed against a variety of other factors, the coefficients of the equations providing information about the marginal contribution which these factors make to overall LS (or utility). LS studies have examined a range of issues including pollution (Ferreira & Moro, 2010; Levinson, 2012; Luechinger, 2009; MacKerron & Mourato, 2009; van Praag & Baarsma, 2005), forest fires (Kountouris & Remoundou, 2011), floods (Luechinger & Raschky, 2009), climate and climate change (Ferreira & Moro, 2010; Maddison & Rehdanz, 2011). More recently, researchers have tested the approach with some of the harder to measure elements of ES, such as scenic amenities (Ambrey & Fleming, 2011), and ecosystem diversity (Ambrey & Fleming, 2014). But to the best of our knowledge, no-one has yet attempted to use the LS approach to assess the value of CS - the focus of this paper.

The LS approach lends itself to the valuation of CS in a number of different ways. The approach is neither rooted in the biophysical nor financial domains which are known to impact the values elicited, failing to fully reflect the social-cultural impact of ES (Martin-Lopez, Gomez-Baggethun, Garcia-Llorente, & Montes, 2014). It clearly focuses on the relationship between the environment and human well-being (as measured by the LS of individuals), which forms the root of the development of the ES concept (Martin-Lopez et al., 2014) and aims at the core objective of much welfare economics, namely to maximise (individual and/or social) welfare (utility). It also may be able to make a useful contribution to situations involving 'taboo trade-offs' where morally or culturally it is virtually impossible for an individual to contemplate a financial value for something considered sacred, such as a human life (Daw et al., 2015)[1].

The LS approach assumes that each explanatory factor enters the function in a separable and additive manner, but there is much potential overlap between factors (Stoeckl, Farr, Larson, et al., 2014; Windle & Rolfe, 2005); the implication is that this needs to be tested for before simply entering each factor as a separate contributor to LS. Location specific factors (e.g. scenic views, pollution, climate) also impact people's subjective satisfaction with those factors and/or the importance people assign to those factors as contributors to LS (Costanza et al., 2007). An implication of these location specific factors is that the relationship between CS and LS may vary across geographic regions. Estimating a single (regression) equation for all individuals across a wide geographic region implicitly assumes that all factors contribute similarly to the LS of all individuals in all locations; thus if regional variations are present global estimation techniques will not model relationships well and alternate techniques that address spatial relationships, such as geographically weighted regression (GWR), may be required to avoid biased or invalid estimation results (Bateman, Jones, Lovett, Lake, & Day, 2002).

[1] Making explicit the trade-offs between the well-being of different groups can ensure these issues are not overlooked in policy decisions; this does not assume that offering financial compensation is the solution to such taboo trade-offs.

This paper takes a LS approach to demonstrate a way of assessing the value of CS, whilst also employing an estimation technique that can account for potential spatial variations in the relationship between LS and CS (not previously used in LS valuation studies). Here, we use the Great Barrier Reef World Heritage Area (GBR) as a case study to ask:

1. Do reported levels of satisfaction with the CS associated with the GBR contribute to the overall satisfaction with life reported by residents, and is there spatial variation within this relationship?
2. Can we use coefficients from the LS model to generate valid estimates of (some of) the CS values of the GBR?

Within section 2 we briefly describe our case study area, the development of our model, the selection of our independent variables, and the design of our questionnaire. We also describe how the data were collected, our estimation techniques, and our method of estimating the value of CS. Results are provided and discussed in section 3, whilst section 4 draws conclusions from this research.

2 Materials and methods

2.1 Case study area

The GBR, situated in the Coral Sea off the coast of Queensland, Australia, is the world's largest reef system comprising 348,700 km^2 and was proclaimed a World Heritage Area in 1981 (UNESCO World Heritage Convention, 1981). There have been marked increases in the amount of nutrients, sediments and pesticides flowing into the GBR since European settlement (Furnas, 2003; Kroon et al., 2012; Lewis et al., 2009) and substantive declines in coral cover in areas where sediment loads have increased the most (De'ath, Fabricius, Sweatman, & Puotinen, 2012). The GBR is close to being added to the World Heritage in Danger list (UNESCO World Heritage Centre, 2014), but many desire to further develop the ports and mines along the coast. It is therefore important to assess both the benefits and the costs of further economic growth, encompassing the harder to value environmental and social impacts in addition to the economic impact of development.

Numerous studies in recent decades have generated estimates of the monetary worth of various values associated with the GBR, although there have been many more studies of the services provided via markets (predominantly use values) where values are relatively easy to estimate (Stoeckl et al., 2011). Studies of non-use values are relatively sparse but include: a contingent valuation study of 'vicarious' users (tourists and Australian residents living outside the GBR catchment) (Hundloe, Vanclay, & Carter, 1987); a choice modelling study of the non-use value of an estuary within the GBR catchment (Windle & Rolfe, 2005); and an attempt to estimate the collective value of numerous community defined benefits, grouped together to represent either provisioning services, regulation and maintenance services, cultural services, or a mix of cultural and regulation and maintenance service (Stoeckl, Farr, Larson, et al., 2014). Thus, the existing body of research does much to highlight use values (that may be enhanced by development) but may fail to sufficiently highlight some of the CS (particularly the non-use ones) provided by the GBR that may be lost if the Reef is not conserved. As discussed earlier, failing to fully reflect all aspects of ES in a valuation may result in misguided policy decisions; hence the importance of estimating a value of the (non-use) CS provided by the GBR.

FIGURE 1 MAP FROM SEPARATE EPS FILE TO BE INSERTED HERE

Figure 1 Study area: The Great Barrier Reef World Heritage Area

2.2 Questionnaire design and data collection

LS research assumes that each individual *i*'s life satisfaction (LS_i) is affected by numerous factors (X_i). Our hypothesis is that these numerous factors include values associated with the CS provided by the GBR (CSV_i), resulting in a conceptual model of the form:

$$LS_i = f\,(X_i, CSV_i) \qquad (1)$$

Our first task, therefore, was to determine how best to measure LS_i, X_i and CSV_i and how to empirically estimate the relationship between them.

There are numerous different ways of measuring LS – all of which involve asking respondents to indicate how 'satisfied' they are, either with life overall, or with various aspects of life (e.g. the

Cantril Ladder (Cantril, 1965)). We chose to use a single question, asking respondents to consider their own life and personal circumstances, and to then indicate, on a 5 point Likert scale, how satisfied they were with life overall.

As regard 'other' variables (X_i):, we used a range of socio-demographic and economic variables informed by those variables which previous researchers have found to be significantly related to LS (a summary of articles using different determinants is provided in Appendix 1). As such, our survey included numerous background questions about age, gender, marital status, income, etc. (Table 2 summarises those variables retained within our final model, Appendix 2 sets out all the variables tested as part of our empirical analysis).

Determining how best to assess CSV_i was a little more problemmatic. If wishing to assess the contribution a standard economic good (say, *widgets)* makes to overall LS (wellbeing, or utility), one would ideally count the number of *widgets* consumed by each individual over a given period of time (say one year), and include that in the regression equation. Within an environmental context, if seeking to place a value on conservation activities for a particular species, one could include a measure of population size within the regression. However, this cannot easily be done for CS values (particularly those relating to the non-use elements that comprise a significent portion of total CS), as there is no meaningful way to measure quantity, since the service is either there (for all people) or not. We are seeking to value the benefit of the GBR continuing to exist as opposed to becoming marginally less available, thus we estimate a total value (all or nothing), rather than a marginal value, where the problem of 'scope' may be significant[2]. Still, it is difficult to determine how to measure this – particularly given the complex inter-relationships between various use and non-use values (or between cultural and other ES). We chose to focus on people's perceptions of their satisfaction with

[2] When estimating marginal values, this can vary depending on the starting point; e.g., people are likely to be willing to pay a lot more to save 100 animals that are the last of their species than they would be save 100 animals where the species is far from extinct. Estimating the total rather than marginal value should reduce this problem.

numerous ES (and other) values using a coarse Likert scale to gauge 'satisfaction' and principal components analysis (PCA)[3] to identify items associated with CS.

People's perceptions were gathered using surveys. The questionnaire included a list of 18 different community defined benefits representing many different services provided by the GBR (Table 1), developed from a literature review and by consulting regional stakeholders/managers/decision makers during workshops held in Cairns, Brisbane and Townsville (see Stoeckl, Farr, Jarvis, et al. (2014) for details of literature review and workshops). The questionnaire asked, amongst other things, *"How satisfied are you with each item below? Indicate whether all is well (very satisfied) or if there is something wrong (very unsatisfied)".* Responses were recorded on a 5-point scale.

Table 1 Community-defined benefits assessed in the questionnaire

The status/health of the region's: *Beaches and islands – undeveloped and uncrowded *Beaches and islands – without visible rubbish (bottles, plastic) *Coral reefs *Reef fish *Iconic marine species (whales, dugongs, turtles) *Oceans – clear water (with good underwater visibility) *Mangroves and wetlands
*The chances that the GBR World Heritage Area will be preserved for future generations
The benefits you receive from: The reef-based tourism industry The commercial fishing sector The mining and agricultural sectors Cheap shipping transport
The health/status of traditional/indigenous cultural values
The status of your 'bragging rights' – knowing that people envy you for living near the Great Barrier Reef
Your opportunities to: Eat fresh locally caught seafood Go fishing, spear-fishing or crabbing

[3] Using PCA is important to reduce the risk of bias due to non-separability of preferences, which can increase or decrease the importance or value of a feature by relatively large amounts depending on the nature of the non-separability (Carbone & Kerry Smith, 2013).

Spend time on the beach, go swimming, diving etc.
Go boating, sailing or jet-skiing
* Benefits included within the composite single variable for CS values as a result of PCA

Some of the community defined benefits listed in Table 1 clearly represented provisioning services. Of these, some were strongly associated with the market and were priced, such as benefiting from the jobs and incomes associated with the commercial fishing industry, whilst others were non-priced e.g. being able to eat fresh locally caught seafood. Other benefits were arguably more strongly associated with CS values (e.g. 'having' healthy iconic marine species, reefs and reef fish, knowing that the GBR will be preserved for future generations). At issue here is the problem of deciding which benefit(s) to use as a proxy for CS values.

This is a non-trivial problem; ecosystems are complex, composed of non-linear, interdependent components, and the value of the services they produce are interdependent and overlapping (Costanza et al., 1997). Therefore, we sought to develop a collective measure, combining responses to questions about satisfaction with benefits most closely associated with measures of CS, such collective measures of value having been recommended over single measures (Stoeckl, Farr, Larson, et al., 2014; Windle & Rolfe, 2005).

In the first instance, we checked for separability by looking at correlation coefficients and using PCA (with Varimax rotation and Kaiser normalization), finding that these 18 benefits collapsed into 5 separable factors. The factors, and the benefits which were grouped into each factor resulting from the PCA, along with the factor scores, are set out within Appendix 3. The groupings were the same as those found by Larson, Stoeckl, Farr, and Esparon (2014) and Stoeckl, Farr, Larson, et al. (2014) who grouped the benefits based on importance (rather than satisfaction) scores; thus the groupings appear robust to whichever measure is chosen. Having identified that the responses to 8 of these questions did, in fact, appear to be 'separable' to responses about other benefits (the starred variables in Table 1), we generated a single variable for CS values, based on the median level of 'satisfaction' associated with each response; the frequencies of the responses to these questions can be seen in Figure 2.

Importantly, this proxy for CS values focuses on residents' perceptions and does not consider the actual condition of the GBR. It is noted, however, that respondent's perceptions have frequently and successfully been used within LS studies, including perceived water quality (Guardiola, González-Gómez, & Lendechy Grajales, 2013), perceived aircraft noise (van Praag & Baarsma, 2005) and self-assessed perceptions of health (Diener, Suh, Lucas, & Smith, 1999). Relatedly, researchers have found evidence to suggest that perceptions (of water quality) do a better job of explaining willingness to pay (for improvements in water quality), than do objective measures (of water quality) (Farr, Stoeckl, Esparon, Larson, & Jarvis, 2014). Thus, it is our attempt to include a measure of CS values within the LS model that adds something new to the literature; use of perceptions (rather than of objective measures) is neither novel nor controversial.

2.3 Sampling / data collection

24 different versions of the questionnaire were generated – each version presenting the list of benefits (Table 1) in a different order, since survey respondents have been found to be highly sensitive to the order in which questions are presented[4] (Cai, Cameron, & Gerdes, 2011; Lasorsa, 2003). Questionnaires were pre-tested amongst colleagues and in a pilot study of 200 residents from 100 different postcodes within the GBR catchment area.

The surveys were mailed out[5] (with explanatory letter) to a geographically stratified random selection of households from postcodes that lay either partially or entirely within the GBR catchment area (Figure 1). Only one half of our residents were sent the full questionnaire where they were asked about both importance and satisfaction of the community defined benefits. The remainder were given a shorter questionnaire only covering the importance of these benefits; thus responses to these had to

[4] Dummy variables representing the order that the questions were asked were incorporated within an enlarged form of the overall OLS model developed by this study; as these 'order of question' dummy variables were not found to be significant our results do not appear to be influenced by question order. Results available on request.

[5] Mail out survey collection was chosen rather than using face to face methods, partly due to time and budget constraints (face to face survey collection over a large geographic area would have incurred a prohibitively high cost) and also to avoid the risk that the presence of the interviewer may introduce bias to the responses. However, it is acknowledged that face to face collection can bring some benefits, and may have improved response rates to our survey. A future research opportunity exists to test the use of this alternate methodology for CS valuation purposes.

be excluded from this research as the satisfaction responses were at the core of this study. The Dilman (2007) method was followed; recording returned questionnaires as they arrived, sending a replacement questionnaire to those who had not responded shortly after the first contact, and a further replacement shortly after that. We ensured that an equal number of each version of our questionnaires were sent to each postcode to ensure that the order of the questions did not influence our results. We estimate that 3,977 reached their intended recipient and we received 902 completed questionnaires, giving an overall response rate of 22.7%. Of these 902 completed questionnaires, 515 responses were of the longer version of the survey that were usable within this study, and for almost half of these, 245, the respondent had answered all of the questions required for this analysis[6].

2.4 Econometric issues

Previous LS studies have used a range of estimation techniques, some suitable for categorical or ordinal dependent variables (such as Frey & Stutzer, 1999) and others more appropriate for continuous distributions (for example Easterlin, 1995). Research has been conducted into the effect of using techniques designed for continuous rather than ordinal data; the impact has been found to be small, based on statistical literature (Kromrey & Rendina-Gobioff, 2002; Newsom, 2012). Moreover, insights from the LS research literature (Ferrer‐i‐Carbonell & Frijters, 2004; MacKerron & Mourato, 2009) suggests that the choice of estimation technique (OLS or ordered probit) has little or no impact on the resulting valuations (Ambrey & Fleming, 2011; Levinson, 2012; Luechinger, 2009; Luechinger & Raschky, 2009). Moreover, as Levinson (2012) points out, the LS approach is based on a ratio of coefficients, rather than the absolute effect on the ordinal dependent ratio; as such final estimates of 'value' may be relatively insensitive to the choice of ordinal or continuous techniques;

[6] As frequently found with survey based social sciences studies, there is a possibility of sample selection bias; it is possible that there are differences in preferences between those people who do fully complete and return the survey and those who chose not to fully answer, or not return the survey at all. Should the sample be biased to include more people to whom CS are important than the proportion in the wider population, then our estimates of the value of CS may be overstated. Future research could attempt to minimize this risk by aiming to improve response rates (perhaps using shorter questionnaires requiring less time to complete or collecting survey responses face to face rather than by mail) and by adopting analytical techniques that control for potential sampling bias (the lack of a sufficiently large sample size prevented such techniques being adopted here).

this conclusion is confirmed by others (Welsch & Kühling, 2009). As such, it appears that the use of continuous techniques may be appropriate.

A more neglected econometric issue is space/location (MacKerron, 2012). Some researchers have used spatially derived data within their analysis including, for example, variables that indicate proximity to features such as the coast, landfill sites, airports, major roads (Brereton, Clinch, & Ferreira, 2008). Researchers have also included measures of climate (specifically rainfall, temperature and wind speed data) (Brereton et al., 2008; Ferreira & Moro, 2010); and local measures of pollution (Luechinger, 2009; MacKerron & Mourato, 2009). But, so far as we are aware, only one study has specifically addressed the issue of spatial variation in the relationship between LS and explanatory variables: Stanca (2010), who sought to determine if the relationships between unemployment, income and LS were 'similar' for countries that were geographically close, concluding that "in order to understand the links between economics and happiness, geography matters" (Stanca, 2010, p. 132). We thus used geographically weighted regression (GWR), a refinement to OLS regression, to estimate our LS model. Our use of GWR is discussed further within Appendix 4.

The final set of variables used in the regression was obtained after a series of estimations; starting from a specification including a wide range of variables suggested by the literature (described within Appendix 1). Insignificant variables were gradually dropped (a list of all the potential explanatory variables tested within the model is set out at Appendix 2). When running these models, we generated a single, OLS 'global' model and also used GWR. We tested for the presence of spatial non-stationarity between explanatory variables and LS with the Koenker BP test, confirming the appropriateness of GWR. Spatial autocorrelation was tested for using the Global Moran's I test which indicated that our final model reflected the inherent spatial nature of the data with no important spatial variable having been omitted (thus omitted variable bias is unlikely).

The mean value of each estimated coefficient was calculated for four different Australian Bureau of Statistics' 'SA4 regions' in the GBR catchment area (see Figure 1). If there were fewer than 15 respondents in any region, those observations were combined with observations from the adjacent region, thus ensuring that all groupings included a reasonable proportion of the overall sample (ranging from 16% to 34% of the total), therefore no group was so small that an outlying response could significantly distort the region's average.

Recognising that endogeneity could be present (a common problem with LS studies (Kountouris & Remoundou, 2011; Luechinger, 2009)) (particularly given the potential for simultaneity between our indicators of satisfaction with CS and overall LS), we conducted the Wu-Hausman (Hausman, 1978; Wu, 1973) and Durbin (Durbin, 1954) tests. These tests provided no evidence of its presence, suggesting that the measures of both satisfaction with CS and income are exogenous, and that use of instrumental variables would not be appropriate[7].

2.5 Using coefficients from the model to generate a monetary estimate of the value of cultural ecosystem services

Most LS studies use coefficients from the LS model to calculate the marginal rate of substitution between income and some other variable (e.g. pollution). This is entirely appropriate if working with variables for which marginal changes are possible, but is not appropriate to think about 'marginal' changes in quantity when considering the future of a non-rivalrous common-property good such as the GBR; the Reef either will be preserved for future generations, or it will be allowed to deteriorate and die. That said, it IS possible to have marginal changes in quality: it could be preserved in excellent, good, or some other condition. Our proxy for CS values is far from perfect but it does incorporate a measure of people's perceptions about the state of the region (specifically, satisfaction with the quality of various aspects of the GBR such as coral reefs, reef fish). Moreover, for the moment we can offer no alternative variable that is both theoretically correct and empirically practical. We thus replicate the estimation process. That is, we estimate the (average) amount of additional income that each respondent would need to adequately compensate them (i.e. to keep overall LS constant) should there be a reduction in their satisfaction with the various CS values associated with the GBR.

[7] Details of test results and instrumental variables included are available on request.

$$\text{Average compensation per person} = \frac{\frac{\partial LS}{\partial CSV}}{\frac{\partial LS}{\partial Income}} \times \Delta CSV$$

The ΔCSV included here is that resulting from satisfaction levels falling from current levels to zero. A single estimate of 'value' was calculated using the coefficients from the GWR model, and 'values' were also estimated for each of the four regions, using the spatially differentiated coefficients to do so. We then multiply this per-capita figure by the number of employed persons in the region, to generate an aggregate estimate of the value of CS[8].

3 Results and Discussion

3.1 The estimated regression model

Our analysis uses only a subset of all responses (n=245): those who answered every question, and for which we had enough locational information to identify the latitude and longitude of the residence, so that GWR could be used. The survey respondent's home locations are indicated in the map at Figure 1 (drawn at a scale that prevents identification of respondents to preserve confidentiality).

The distribution of responses to the question about LS, and the distribution of responses to the questions regarding satisfaction with the cultural ecosystem services (CSV) associated with the GBR are shown in Figure 2, while Table 2 provides summary statistics for the other variables used in the LS model (the X's)[9].

[8] It should be recognised there is no assumption that this compensation be actually offered; neither are we proposing that the residents of the region would be willing to accept a monetary compensation for any degradation in the CS provided by the GBR. Specifically, this calculation has estimated the amount of income that would generate the equivalent impact on LS as that currently provided by the CS that the residents enjoy.

[9] The original specification of the model included a far larger number of different factors, many of these were found to be statistically insignificant and were thus excluded from the final model. The full list of variables considered are set out in Appendix 2.

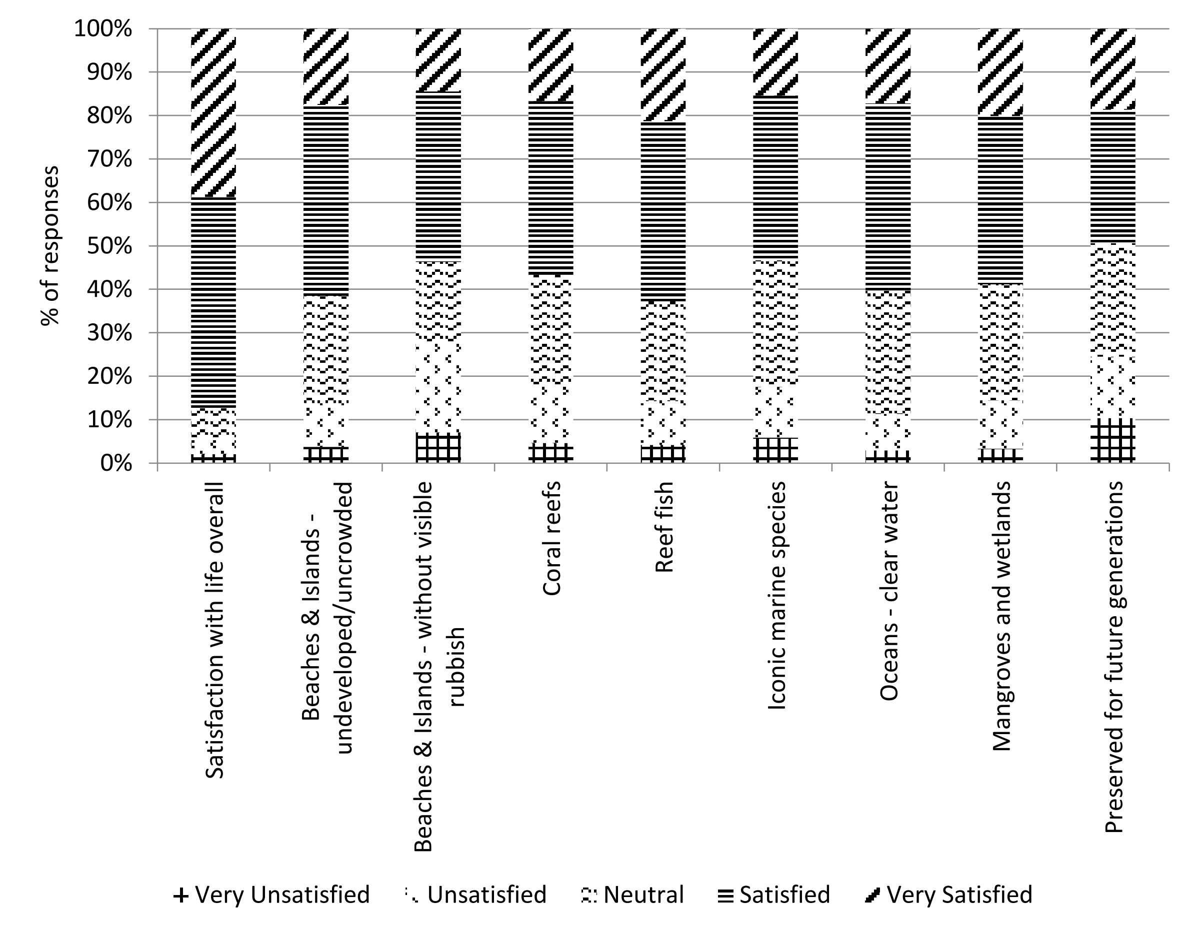

Figure 2 Responses to questions regarding satisfaction with life overall and with the cultural ecosystem services values associated with the GBR

Table 2 Other explanatory variables used in the LS model

Variable	**Mean (or proportion if dummy variable)**	**Std. Dev.**	**Skew**	**Kurtosis**
Age^2: expressed in years	3,257.92	1,546.42	0.52	0.05
Male (Dummy variable set to 1 if male, otherwise 0)	0.52	0.50	a	a
Married (Dummy variable set to 1 if married or in legal partnership, otherwise 0)	0.75	0.43	a	a
Year 12 or higher (Dummy variable set to 1 if completed year 12 at high school or higher, otherwise 0)	0.77	0.42	a	a
Australian born (Dummy variable set to 1 if born in Australia, otherwise 0)	0.81	0.39	a	a

Income: individual income in $[10]	51,373.27	33,889.68	1.20	2.51

a: skew and kurtosis are not relevant for categorical data.

The results from the OLS, the overall GWR and each of the four models (Cairns, Townsville, Mackay and Fitzroy, in order from north to south) are presented in Table 3.

The Koenker BP Statistic was 13.138 significant at 10% level, indicating that spatial variations are present. The GWR estimation process provided a higher adjusted R^2 statistic and a lower AIC than the global OLS model indicating that the GWR models provide better goodness of fit, further confirming the existence of spatial variations. The Global Moran's I test value was -0.007, not significant even at 10% level; this confirms that spatial autocorrelation is not present in the regression residuals, indicating the model reflects the inherent spatial nature of the data with no important spatial variable having been omitted.

We thus focus on the GWR results, firstly considering the overall model. All explanatory variables were significant at 5% level. The adjusted R^2 is fairly low at .140, but is consistent with previous LS research.

The signs and statistical significance of socio-demographic variables were as expected from the literature:

> age had a statistically significant and positive relationship with LS (Ambrey & Fleming, 2014; MacKerron & Mourato, 2009);

> females were, on average, more satisfied with life than male respondents as were those who were married or in legal partnership (Brereton et al., 2008; Ferrer-i-Carbonell & Gowdy, 2007);

[10] For this study survey respondents were asked the question "On average, how much pre-tax income does your household earn each year?", with respondents selecting the appropriate category from a list with the midpoint of each category used for the study. Household income was then converted to individual income using the modified OECD scale adopted by the ABS (Australian Bureau of Statistics, 2010)

those who had completed year 12 education or above were more satisfied than those who had not (Frey & Stutzer, 2000), although we note that the coefficient may also be incorporating the indirect effect that education has on improving health (Dolan, Peasgood, & White, 2008);

those born in Australia had higher LS than migrants (confirming earlier research that found living within your country of origin increases LS (Frey & Stutzer, 1999));

income had a significant and positive impact on LS (Ferreira & Moro, 2010; Ferrer‐i‐Carbonell & Frijters, 2004).

Our proxy for CS values was highly significant. We are not aware of previous research that has considered the interaction between CS values and overall LS; however, a positive relationship has been found between LS and sustainable development (Zidanšek, 2007), ecosystem diversity (Ambrey & Fleming, 2014), and being concerned about the extinction of species (Ferrer-i-Carbonell & Gowdy, 2007). Thus, the finding that the ES are important to LS accords with our expectations and with findings from studies in a similar field.

For the regional models, the R^2 is highest for the most northern region (Cairns) followed by Townsville and then the other regions. This indicates that the model does a slightly better job explaining the relationship between the independent variables and overall LS in the north than the south.

Table 3 GWR and OLS model results for dependent variable: Satisfaction with Life Overall

	GWR model Cairns	**GWR model Townsville**	**GWR model Mackay**	**GWR model Fitzroy**	**GWR model Overall**	**OLS global model**
Variables	**Coefficients Standard errors in brackets**					
Age^2	.00014***	.00014***	.00014***	.00015***	.00014***	.00015***
	(.00004)	(.00004)	(.00004)	(.00004)	(.00004)	(.00004)
Male	-.3447***	-.2879**	-.2320**	-.2014*	-.2727**	-.2790**
	(.1208)	(.1117)	(.1117)	(.1251)	(.1179)	(.1089)

Married	.5143***	.3828***	.2333*	.0985	.3232**	.3073**
	(.1394)	(.1279)	(.1265)	(.1429)	(.1349)	(.1237)
Year 12 or higher	.5295***	.4788***	.4033***	.3199**	.4398***	.4231***
	(.1511)	(.1403)	(.1403)	(.1576)	(.1480)	(.1375)
Australian born	.4863***	.3664**	.2286	.1267	.3162**	.3204**
	(.1538)	(.1426)	(.1428)	(.1654)	(.1517)	(.1388)
Income	3.012E-06	3.000E-06	4.000E-06**	4.857E-06**	3.694E-06*	4.000E-06**
	(2.012E-06)	(2.000E-06)	(2.000E-06)	(2.000E-06)	(2.004E-06)	(2.000E-06)
CSV	.1412**	.1351**	.1314**	.1352**	.1362**	.1467***
	(.0614)	(.0572)	(.0575)	(.0655)	(.0606)	(.0561)
Constant	-.5223	-.3180	-.0826	.0752	-.2357	-.2559
	(.3108)	(.2857)	(.2838)	(.3216)	(.3020)	(.2777)
Sample size	84	40	65	56	245	245
Adjusted R^2					.140	.113
Local R^2	.178	.146	.121	.119		
AIC					603.034	608.375

*** p<0.01, ** p<0.05, * p<0.1

Coefficients also vary across models/regions, with a distinct north/south pattern. Income contributes relatively less to overall LS in the north than in the south: indeed it is not even a significant contributor to overall LS in the two most northern regions[11]. The contribution of other variables is generally greater in the north than the south. This is so for CSV: the models indicate that they are a more important contributor to overall LS for residents of the north than of those in the south.

Tukey Post Hoc tests[12] confirmed the statistical significance (at the 1% level) of differences between each coefficient for each region with three exceptions: (i) the coefficient for age squared for Fitzroy was significantly different to all other regions, however Cairns and Townsville, and Townsville and Mackay, did not have significant differences, and the coefficients for Cairns and Mackay were only significantly different at the 5% level (ii) the coefficient for income was not significantly different between Cairns and Townsville, and (iii) the coefficient on CSV was not significantly different between Mackay and Fitzroy.

[11] Average incomes of respondents were also higher in the southern regions compared to the north.

[12] Post hoc tests that do not assume equal variances were also tested (Tamhane's T2 test, Dunnett's T3 test, Games-Howell test and Dunnett's C test); all results were the same as the Tukey test results other than for the age squared variable where all regions were significantly different from each other at 1% level other than Townsville and Mackay.

Visual inspection of Figure 1 clearly shows that some of our respondents reside much closer to the coast, and thus the GBR, than others. Virtually all of our sampled properties within Townsville region were very close to the coast; those of Cairns region were also fairly close, although many respondents were further inland on the Atherton Tablelands. However, the survey respondents within Mackay and Fitzroy regions are widely dispersed, respondents from the southern part of the study area were, on average, more than 2.5 times further from the coast than those from the northern section. An inverse relationship is generally expected between protection values applied to environmental assets and distance from the asset, referred to as distance decay (Rolfe & Windle, 2012). Theory suggests that the rate of decay would vary across different ES. Recognising that geographical proximity to the Reef may impact results, a variable measuring proximity to the Reef was included within the regressions. This variable was not significant, suggesting distance decay is not an issue. This confirms observation from other studies of values in the GBR region (Rolfe & Windle, 2012) and accords with theory that distance decay would be small or even zero for non-use values for a unique feature (Pascual et al., 2010) as the GBR is indeed unique and a large component of the total CS value is likely to relate to non-use values.

3.2 Estimating the valuation of cultural ecosystem services provided by the GBR

Table 4 presents our estimates of the additional income that would be required to compensate residents should current (median) levels of satisfaction with CS values drop to zero (equivalent to a situation where residents are neither satisfied nor dissatisfied). These range from almost $30k per capita per annum for Cairns to $17k - $23k per annum per capita in the other regions. Multiplying this amount by the number of employed persons in the GBR region, being 394,878 in total (Australian Bureau of Statistics, 2011), suggests that aggregate ‘regional’ compensation, representing the CS value of the GBR, would be about $8.7 billion per annum. Whilst some studies have attempted to estimate marginal non-use values in the GBR (see, for example the research of Rolfe and colleagues), we know of only one other study that has looked at total values: Stoeckl, Farr, Larson, et al. (2014). They did not focus exclusively on CS, and used a very different methodological approach, but predicted that this group of mainly non-use CS would be worth more than $4 billion per annum associated with the GBR based tourism industry; our results are not inconsistent with theirs.

Table 4 Estimated value of CS provided by the GBR to residents of the regions and overall

	Cairns	**Townsville**	**Mackay**	**Fitzroy**	**Overall**
Income increase required should satisfaction with CSV decline to zero[13]	$29,296	$19,138	$23,001	$16,655	
Number of workers in region	102,879	105,992	84,877	101,130	394,878
Estimated value of the CS provided by the GBR	$3.0bn	$2.0bn	$2.0bn	$1.7bn	$8.7bn

It should be noted that although the coefficient on income is significant overall, and significant within the Mackay and Fitzroy regions, it was not significant in the Cairns or Townsville regions. This result could be interpreted to mean that there is no amount of income that could adequately recompense the residents of these regions should the CS cease to satisfy them; that is the CS is 'priceless' to the residents of those regions. In accordance with the law of diminishing marginal utility, once income reaches a certain level then further increases to income will only have a very small impact on utility; the insignificant income coefficients found here indicate that for many of the residents in the northern regions this position may have been reached and thus additional income is unable to compensate for the loss of another benefit (the CS of the GBR) which contributes significantly towards LS. Furthermore, the finding of an insignificant coefficient for income in explaining LS (which results in the large value assigned to CS) in these regions is not unique to this study (and hence should not be dismissed as a function of a weakness in the study); indeed, this is the core of Easterlin's income paradox (Easterlin, 1973).

[13] Further investigating any possible impact of proximity to the reef (discussed in section 3.1), the income increase required as compensation was re-estimated excluding those survey respondents residing furthest from the reef, such that the average distance to the reef for each of the southern regions was the same for that of the north. For this reduced sample, the income increase required per capita increased by $2k and decreased by $3k for Mackay and Fitzroy respectively; these changes had a small impact on overall valuation of CS provided by GBR (estimated value reduces to $8.5bn) but did not impact our relative finding that the CS are valued more by the residents of the north compared to the south of the catchment.

This research has clearly identified spatial variations in the value placed on CS, that is, CS are relatively more important to LS for residents in the north whilst income is relatively more important to LS for those in the south. However, cross-sectional research cannot identify the causality within this relationship: does increased incomes cause someone to value money more and place less value on CS? Or do higher paying regions attract residents who value money relatively highly, whilst regions offering more/better quality CS attract residents who value CS relatively highly? Future research using time-series or panel data could usefully illuminate this important question.

4 Conclusions

This research seeks to extend the existing literature based on the LS approach to environmental valuation. Using the GBR as a case study we have tested if it is, in principle, possible to use this technique to estimate the value of the CS provided by an environmental feature. Our findings are cautiously affirmative – although we stress the need for much further research on methods of using questionnaires to measure CS for use in LS studies.

Our estimate of value indicates that the (non-use) CS provided by the GBR to residents of the catchment are likely to be worth about $8.7 billion per annum; however, this result should be regarded with some caution as our estimate is based on imperfect data, as described above. Our less cautious, and potentially much more significant, finding relates to the observed spatial variation in values: residents of the north appear to gain relatively more satisfaction from CS (and less satisfaction from income) than residents of the south. This highlights the important role that aggregation plays in all non-market valuation studies: it may be possible to calculate the ‘average’ amount of compensation required to maintain utility should the environment be damaged and ES eroded, but for some individuals, no amount of compensation will ever be enough. Evidently, in this region, it is the residents of the north who will likely feel most aggrieved by development that erodes CS of the GBR.

5 Acknowledgments

This research was conducted with the support of funding from the Tropical Ecosystems Hub of the Australian Government's National Environmental Research Program (Project 10.2).

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New methods for valuing, and for identifying spatial variations, in cultural services: A case study of the Great Barrier Reef

Appendix 1: Factors frequently found to explain variations in Life Satisfaction (LS)

Factors frequently found in studies	Relationship generally found with LS
Age	Either positive (Ambrey & Fleming, 2014; MacKerron & Mourato, 2009) or U shaped (Di Tella, MacCulloch, & Oswald, 2003). Potential non-linearity addressed by including age and/or age squared.
Gender	Females have higher SWB (Brereton, Clinch, & Ferreira, 2008; Ferreira et al., 2013; Ferrer-i-Carbonell & Gowdy, 2007; Welsch, 2007b).
Marital status	Marriage increases LS; divorce associated with lower SWB (Diener, Suh, Lucas, & Smith, 1999).
Living in country of origin (not a foreigner)	Improves SWB (Frey & Stutzer, 1999).
Employed rather than unemployed	Improves SWB (Winkelmann & Winkelmann, 1998); living in high unemployment region, even if not unemployed, reduces SWB (Welsch, 2007b).
Health	Better health improves LS; stronger relationship from subjective rather than objective health measures (Diener et al., 1999).
Higher incomes	Increase SWB (Di Tella et al., 2003; Ferreira & Moro, 2010; Ferrer-i-Carbonell & Frijters, 2004; Welsch, 2002), but alternate research found a negligible/statistically insignificant relationship (Easterlin, 1995), and recent research has begun to investigate potential endogeneity issues. Relative income (both to others and to previous periods) (Easterlin, 1995, 2003), future material aspirations and their relationship to anticipated future income levels (Easterlin, 1995, 2001), and previous income levels (reflecting habituation effect) (Menz & Welsch, 2010) may be important.

Factors frequently found in studies	Relationship generally found with LS
Higher education levels	Increases LS (Frey & Stutzer, 2000). However effect may be indirect as increased education is likely to increase incomes (Diener et al., 1999) and/or education has an indirect impact on improving health; education appears to be more important when health is excluded from studies (Dolan, Peasgood, & White, 2008).
Quality of social capital	Improves SWB; includes measures such as political stability (Abdallah, Thompson, & Marks, 2008), degree of freedom and personal choice (Stanca, 2010), and trust in others or society (Engelbrecht, 2009).
Climatic and environmental factors	Extreme climates (Frijters & Praag, 1998; Maddison & Rehdanz, 2011), pollution, including air pollution (MacKerron & Mourato, 2009; Welsch, 2007a) and noise levels (van Praag & Baarsma, 2005), and environmental disasters, such as draught (Carroll, Frijters, & Shields, 2009), forest fires (Kountouris & Remoundou, 2011) and flooding (Luechinger & Raschky, 2009) reduce SWB. SWB is enhanced by high quality environmental amenities, such as living near the coast or having good views (Ambrey & Fleming, 2011; Brereton et al., 2008), ecosystem diversity (Ambrey & Fleming, 2014), the quality of ecosystem services (Abdallah et al., 2008; Vemuri & Costanza, 2006), and environmental sustainability (Zidanšek, 2007).
Genetic factors	Studies of identical and non-identical twins and siblings have established that genetic/hereditary factors are key determinants of LS and 'happiness (Lyubomirsky, Sheldon, & Schkade, 2005; Zidanšek, 2007). Genetic factors have been estimated to explain between 39% and 58% (Tellegen et al., 1988) and between 40% and 55% (Diener et al., 1999) of differences; in young children (Braungart, Plomin, DeFries, & Fulker, 1992) the estimated influence of genetic factors is between 35% and 57%.

Appendix 2: List of potential explanatory variables tested within the model

Category	Objective	Subjective
Demographic	Age and age squared	
	Gender	
	Marital status	
	Educated to year 12 or above	
	Educated at university or above	
	How many adults/children live with you	
	Household size	
	Born in Australia	
	Born in Queensland	
	Indigenous status	
Economic	Income and Ln Income[1]	
	Various sources of household income (denoted by dummy variables for different industries)	
	Unemployment rate in region where live	
	Concentration of different industry sectors in region where live	Responses to various survey questions concerning importance & satisfaction in Table 1.
	Population density in region where live[2]	
	Relative socio-economic index of advantage and disadvantage for region where live	
	% households in poverty for region where live	
	Average income in region where live	
	Death rates in region where live	

[1] Previous studies have found that taking the natural log of income can improve the explanatory power of the model. We did this, but found little difference (also found by Welsch, 2002) and use the linear version for ease of interpretation of results.

[2] Cairns, is far more densely populated with 10.2 persons per km2 compared to 1.8 - 2.8 for the other regions (ABS from census 2011). Population density has been found to impact overall LS, although from prior research the direction of impact remains unclear. A positive effect has been found and attributed to the better range of amenities available (Brereton et al., 2008) whilst alternate research found a negative effect (Maddison & Rehdanz, 2011). For this study, the relationship between population density and overall LS was not found to be significant.

Category	Objective	Subjective
Environment	Rainfall in previous year – mm, number of days of rain, number days of intense (>100mm) rain, number of days no rain Total suspended sediment load in river closest to where live Dissolved inorganic nitrogen in river closest to where live Water turbidity in GBR lagoon closest to where live Vegetation type where live Soil type where live Estimates of species richness for birds, reptiles, amphibians and mammals in region where live	Responses to various survey questions concerning importance & satisfaction in Table 1.
Social	Crimes per head in region where live Remoteness indicator for region where live (dummy variables denoting very remote, remote, outer regional, inner regional)	Responses to various survey questions concerning importance & satisfaction in Table 1.
Genetic	Like most other researchers, we did not have access to genetic data and thus were unable to explicitly include these factors in our study.	

Appendix 3: Factor scores from principal component analysis (PCA) for satisfaction scores for community-defined benefits assessed in the questionnaire

Factor 1	**Factor 2**	**Factor 3**	**Factors 4 & 5**
Cultural ecosystem services (CS)	**Economic benefits**	**Benefits from activities**	**Other benefits**
Beaches and islands – undeveloped and uncrowded (.736)	The reef-based tourism industry (.749)	Eat fresh locally caught seafood (.597)	The health/status of traditional/indigenous cultural values (.689)

Factor 1	Factor 2	Factor 3	Factors 4 & 5
Cultural ecosystem services (CS)	**Economic benefits**	**Benefits from activities**	**Other benefits**
Beaches and islands – without visible rubbish (bottles, plastic) (.793)	The commercial fishing sector (.812)	Go fishing, spear-fishing or crabbing (.861)	The status of your 'bragging rights' – knowing that people envy you for living near the Great Barrier Reef (.794)
Coral reefs (.844)	The mining and agricultural sectors (.750)	Spend time on the beach, go swimming, diving etc. (.807)	
Reef fish (.863)	Cheap shipping transport (.762)	Go boating, sailing or jet-skiing (.857)	
Iconic marine species (whales, dugongs, turtles) (.821)			
Oceans – clear water (with good underwater visibility) (.824)			
Mangroves and wetlands (.801)			
The chances that the GBRWHA will be preserved for future generations (.644)			

Appendix 4: Brief description of the use of geographically weighted regression within the analysis

We thus used geographically weighted regression (GWR) to estimate our LS model. GWR is a refinement to OLS regression, and can be defined by the equation:

$$Y_i = \beta_0 (u_i,v_i) + \Sigma_k \beta_k (u_i,v_i) X_{ik} + \varepsilon_i$$

Where Y_i is the dependent variable, X_i is the corresponding covariate vector of variables, (u_i,v_i) denotes the coordinates of the ith point in space and $\beta_k (u_i,v_i)$ is a realisation of the continuous function $\beta_k (u_i,v_i)$ at point i; thus the equation recognises that spatial variations in the relationships between variables may exist and allows estimates of the localised parameters to be obtained for any point in space (Fotheringham, Brunsdon, & Charlton, 2002, p. 52). Local standard errors are also calculated in addition to local parameter estimates, based on using the normalised residual sum of squares from the local regression equations (Fotheringham et al., 2002).

The regression was estimated using ArcGIS. When estimating the regression for each location the AIC method was used to determine the kernel (the optimal distance/number of neighbours to be used), rather than the researchers imposing their view of the appropriate kernal.

The mean value of each estimated coefficient was calculated for two different geographic areas: (1) for four different Australian Bureau of Statistics' 'SA4 regions' in the GBR catchment area (shown in Figure 1); and (2) for 10 different local government areas (LGA) in that same region. If there were fewer than 15 respondents in any region, those observations were combined with observations from the adjacent region, thus ensuring that all groupings included a reasonable proportion of the overall sample (ranging from 16% to 34% of the total for SA4 groupings), therefore no group was so small that an outlying response could significantly distort the region's average. The geographical patterns were very similar in both cases, so we report only those associated with the SA4 regions, but results by LGA are available on request.

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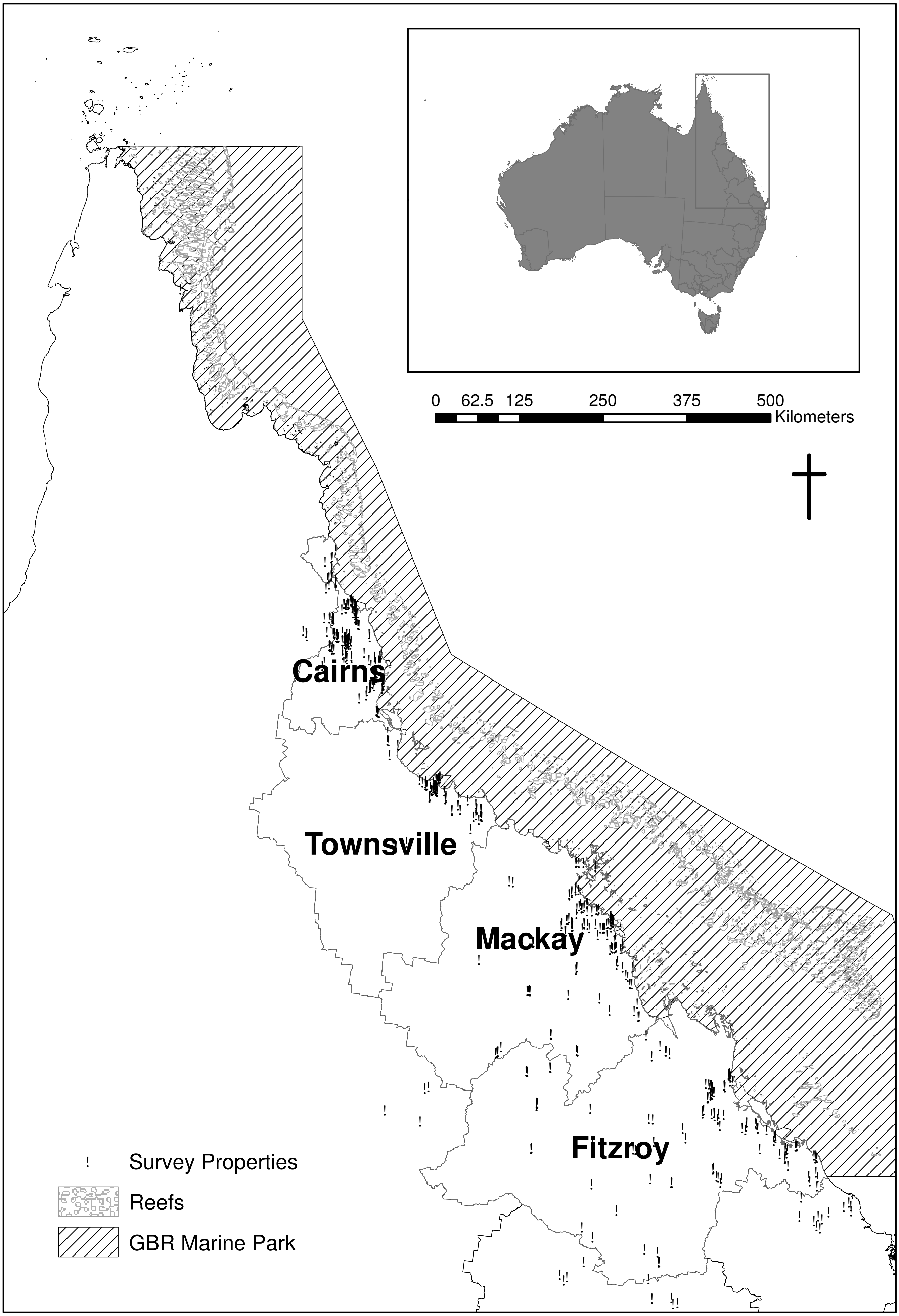
Figure 1



0
62.5
125
250
375
500
Kilometers
Cairns
Townsville
Mackay
Fitzroy
Survey Properties
Reefs
GBR Marine Park

New methods for valuing, and for identifying spatial variations, in cultural services: A case study of the Great Barrier Reef

Response to Reviewers comments

The reviewers raised three items that needed our attention. We have set out below how we have dealt with these in the revised manuscript.

1- you state that CS are thus essentially a hybrid of use and non-use values citing Pascual et al., 2010. However, services generate benefits, if they satisfy needs / wants, and the benefits are assigned values by people. See Braat & De Groot, 2012 (Ecosystem Services 1:4-15). If you want to cut this chain short then do not equate services to values but use e.g. "services are assigned values".

Response: To reflect this comment we have rewritten the relevant paragraph on page 3 and have included a reference to the paper recommended. We have now more clearly stated that the various ecosystem services provide benefits to individuals, which can be of both use and non-use nature, and individuals then assign values to these. Thank you for this comment, which has enabled us to clarify that section of our paper.

2- there are several typos in the introduction and methods sections.

Response: Corrections have been made to the various typos across pages 3, 5, 7, 9 and 11. We apologise that these mistakes were included within our previous submission.

Page 3 – issued corrected to issues

Page 5 – describing corrected to describe

Page 7 – inserted 'a' and 'we' to improve readability, and corrected e.g to e.g., in the footnote

Page 9 – are corrected to were, other corrected to others

Page 11 – was corrected to were and 'the' inserted to improve readability

3- You use PCA without having given the full term.

Response: We first refer to PCA on page 8; we have now written principal components analysis out in full, and shown PCA as the abbreviation for this term.