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# A new approach to the problem of overlapping values: A case study in Australia's Great Barrier Reef

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ABSTRACT

Estimating the value of entire ecosystems in monetary units is difficult because they are complex systems composed of non-linear, interdependent components and the value of the services they produce are interdependent and overlapping. Using the Great Barrier Reef (GBR) as a case study, this paper explores a new 'whole ecosystem' approach to assessing both the importance (to overall quality of life) and the monetary value of various community-defined benefits, some of which align with various ecosystem services. We find that provisioning services are considered, by residents, to be less important to their overall quality of life than other ecosystem services. But our analysis suggests that many community-defined benefits are overlapping. Using statistical techniques to identify and control for these overlapping benefits, we estimate that the collective monetary value of a broad range of services provided by the GBR is likely to be between $15 billion and $20 billion AUS per annum. We acknowledge the limitations of our methods and estimates but show how they highlight the importance of the problem, and open up promising avenues for further research. With further refinement and development, radically different 'whole ecosystem' valuation approaches like these may eventually become viable alternatives to the more common additive approaches.



## 1. Introduction

Valuation is about assessing trade-offs towards achieving a goal (Farber et al., 2002). All decisions that involve trade-offs involve valuation, either implicitly or explicitly (Costanza et al., 2011). When assessing trade-offs, one must be clear about the goal. Ecosystem services are defined as the benefits people derive from ecosystems – the support of sustainable human well-being that ecosystems provide (Costanza et al., 1997; Millennium Ecosystem Assessment (MEA), 2005). The value of ecosystem services is therefore the relative contribution of ecosystems to that goal. There are multiple ways to assess this contribution, some of which are based on individual's perceptions of the benefits they derive. But the support of sustainable human well-being is a much larger goal (Costanza, 2000) and individual's perceptions are limited and often biased (Kahneman, 2011). Therefore, we also need to include methods to assess benefits to individuals that are not well perceived, benefits to whole communities, and benefits to sustainability (Costanza, 2000).

In empirical studies, valuation tasks are often conceptualised with reference to some version of a total economic value (TEV) framework (Pascal et al., 2010). This framework facilitates valuation by dividing benefits into "direct use values" (for example provisioning services) that can often be valued using market-based approaches and "non-use" or "indirect use" values (for example regulating, cultural, and supporting services) that often require the adoption of stated preference approaches or approaches that do not rely on current preferences. Some researchers only seek to generate estimates of the value of one particular type of service (e.g. recreation) in monetary units, but others require information about multiple services or the value of an entire area, or ecosystem. There are many examples in the literature where researchers have generated or collected estimates of the value of several services associated with an ecosystem in monetary units, and then added. In these instances, TEV is thus conceptually calculated in two steps. First, the social value of each service is estimated by, in essence, summing individuals' values for each service. Second, TEV is calculated by summing the social value of each service.

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Importantly, this approach assumes that

(a) the marginal utility of income is constant across all individuals, meaning that social value of a service can be estimated by simply adding individual benefits (Alder and Posner, 1999);
(b) substitution effects and budget constraints are properly accounted for (Hoehn and Randall, 1989);
(c) general equilibrium effects are either minimal or are controlled for when estimating the social value of each component (De Groot et al., 2002); and
(d) all benefits contribute to the utility of each individual in an *additively separable* manner, so that total values can be estimated by adding the value of services without the risk of double counting (Carbone and Smith, 2013; De Groot et al., 2002).

All of these conditions are unlikely to hold in all situations.

The last point (d) is particularly pertinent for valuing entire ecosystems, because they are complex systems composed of non-linear, interdependent components (Koch et al., 2009). As such, it is difficult to separate each individual ecosystem service (Fu et al., 2011). Regulating services, for example, involve a variety of vital processes that support functioning ecosystems. As such, to include both regulating and other ecosystem services (benefits) in valuation exercises, might be double-counting (Balmford et al., 2011; Fisher and Turner, 2008; Fu et al., 2011; Hein et al., 2006).

However, ecosystem services can also be thought of as "joint products" (Costanza et al., 1997). For example, regulating and other services of ecosystems are all produced simultaneously and jointly as a function of the operation of the interdependent complex system. An analogy would be a factory that produces multiple products jointly. Each product can then be valued separately and the total value of the factory's output is the additive sum of the values of all the products with no double counting. What makes a product separable for the purposes of valuation, is not, therefore, the production process (joint products can be separable) but rather the consumption or use process.

This problem of inter-related consumption or use has long been acknowledged by economists and much economics literature relating to systems of demand for market goods (e.g. food, housing, beverages) discusses the importance of separability (Elger and Jones, 2008; LaFrance, 1993; Moschini, 2001). In the environmental/ecological literature, it is more common to refer to the (related) problem of 'overlapping' values (Balmford et al., 2011), but the key point remains: those interested in estimating the value of an entire ecosystem, may need to approach the problem from a 'whole ecosystem' perspective (Loomis et al., 2000) – unless it is possible to first establish that individual ecosystem services are separable (in consumption or use), and thus additive. It is on that problem which this paper focuses.

Costanza et al. (1989) considered a 'whole ecosystem' approach based on net primary production and energy analysis techniques – which, interestingly, generated final estimates of value that closely approximated estimates generated by adding (hopefully) separable values (Costanza et al., 1997). Here, we outline an entirely different, albeit still 'whole ecosytem', approach. Specifically, using the Great Barrier Reef World Heritage Area (GBRWHA) as a case study, we trial a novel approach to the problem of attempting to value an entire ecosystem based on community defined benefits. We borrow ideas from a range of different methodological approaches, including the emerging body of literature that focuses on life satisfaction. We use data collected from more than 1500 residents of the Great Barrier Reef catchment area (GBRCA) – that provide information about people's perceptions of the importance of 18 different community defined benefits (some of which relate to ecosystem services provided by the GBRWHA, and some which do not) to their overall quality of life. Data constraints prevent us from being able to rigorously assess the separability of those benefits, but we use correlation coefficients and principal components analysis to identify several items that are likely to be 'inseparable' (or overlapping). These are grouped together, generating composite benefits that can be validly compared, thus providing information about the likely value of these benefits *relative* to one another[1] and allowing us to generate an estimate of the collective value (expressed in monetary units) of all community-defined benefits associated with the GBRWHA that are considered in this paper.

## 2. Methods

We estimate the total economic value of the GBR by: first ranking 'separable' groups of benefits based on importance; second selecting benchmark values associated with the separable market benefits; and last calculating total value assuming that the GBR catchment area would need to be paid at least the equivalent of that market benefit in compensation for the loss of the industry, as well as for the loss of any other (separable) benefit deemed equally or more important. This approach thus required us to first identify ecosystem benefits (Section 2.2), quantify the relative importance of these benefits (in this instance using the conceptual framework of life satisfaction, Section 2.3), assess the separability of those benefits (Section 2.4) and then calculate the total value of benefits relative to benchmark market values (Section 2.5).

### 2.1. Case study region

The GBRWHA encompasses over 348,000 km$^2$ and extends for more than 2300 km along Australia's northeast coast. This area is not limited to reefs but also includes islands, coastal islands, beaches, estuaries, mangroves, and other parts of the marine system (Fig. 1).

The GBR catchment covers an area of 424,000 km$^2$ and its population, which exceeds one million, is rising rapidly (Great Barrier Reef Marine Park Authority (GBRMPA), 2009). Approximately 20% of all registered businesses in the catchment are associated with the Agriculture, Forestry or Fishing industry (Government Statistician, 2013). The reef-based tourism industry is also important and has been assessed as contributing more than $4 billion per annum to the local economy (Deloitte Access Economics, 2013). However, it is mineral processing that dominates economic activity: in 2001 it accounted for 47% of the region's Gross Value of Production (Productivity Commission, 2003) and in 2011 its total economic stimulus was estimated to be more than $9.2 billion per annum for the statistical divisions that lay along the coast adjacent to the GBR (Rolfe et al., 2011). Despite this large share of GVP, it is worth noting that in relation to the GBRC the total salary spend of this industry in this region is only $3.2 billion (derived from figures provided in Table 2, Rolfe et al., 2011).

Nonetheless, this economic activity has not come without cost: since European settlement there have been measurable increases in sediment, nutrient and pesticide loads in the GBR lagoon (Furnas, 2003; Kroon et al., 2012; Lewis et al., 2009). The increased turbidity that results from higher sediment loads (Fabricius et al., 2013) has degraded the reef in a variety of different ways (Brodie et al., 2012). More specifically, there have been recent precipitous declines in coral cover in areas of the GBR adjacent to where sediment loads have increased the most (De'ath et al., 2012), and in May 2013, the UNESCO World Heritage Committee warned that

[1] Using ideas similar to those explored by Delisle (2012), in a study of traditional hunting in the Torres Strait.

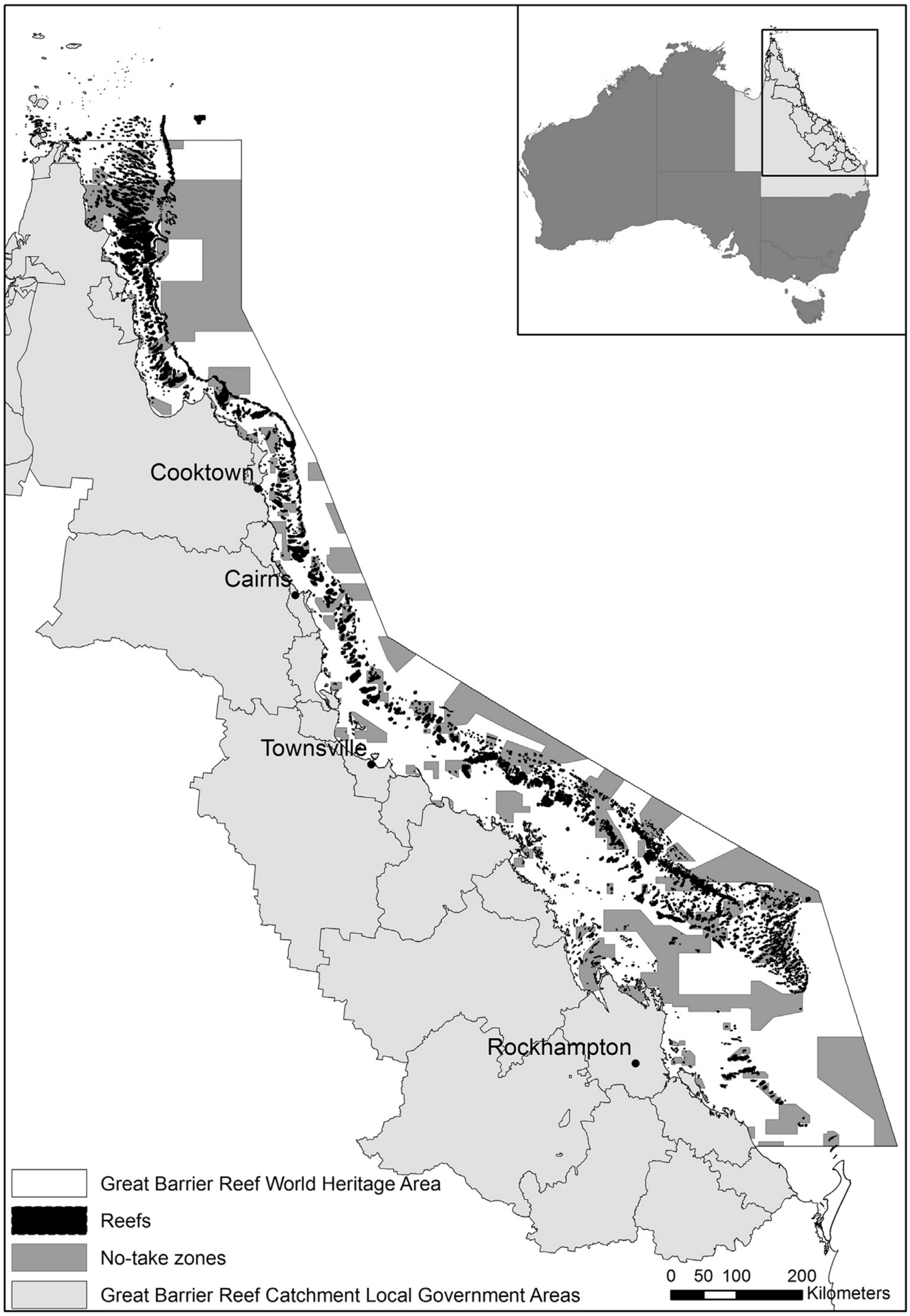


**Fig. 1.** The Great Barrier Reef and local government areas that intersect with river catchments that drain into the GBR lagoon.

the GBR could be added to the List of World Heritage Endangered Sites.

Despite these problems, the economic stimulus that mining provides[2] generates significant external pressure for further mining developments. More minerals cannot be exported without more or larger ports, and all major ports along the GBR coastline are planning expansions (Brodie, 2014). In January 2014, the GBRMPA granted the developers of Abbot Point, a large port to the south of Townsville and adjacent to the GBRWHA, permission to dump sediment from dredging operations within the World Heritage Area. That decision drew much criticism from around the world; concerns mostly focusing on the potential environmental impacts to the GBRWHA (McKirdy, 2014).

The controversy surrounding Abbot Point highlights tensions between those wishing to protect the GBRWHA and those wishing to continue expansion of mining. Clearly, good quality information about the relative 'importance' (or value) of these differing goals could help inform the debate, but while the economic benefits associated with the mining industry are relatively easily quantified (Rolfe et al., 2011), as discussed in the introduction, the economic

[2] Rolfe et al. (2011) estimate that the total economic stimulus of the resources sector is $22.3b across all of Queensland. Interestingly, $10.3b of that within the Statistical Division of Brisbane – more than is accrued across all statistical divisions adjacent to the GBR ($9.2, for the Far North, Northern, Mackay, Fitzroy and Wide-bay statistical divisions combined).

benefits associated with large marine ecosystems such as the GBRWHA are somewhat more difficult to assess.

Worldwide, most marine valuation studies have considered a discrete number of ecosystem services, thus avoiding the double-counting problem. The focus of these studies has been on a relatively narrow range of benefits: recreation (Birol and Cox, 2007; Brander et al., 2007; Mathieu et al., 2003), coastal protection (Costanza et al., 2008; Wilkinson et al., 1999), water purification (Breaux et al., 1995; La Notte et al., 2012), fishing (Hein et al., 2006; McArthur and Boland, 2006; White et al., 2000) and erosion control (Huang et al., 2007; Sathirathai and Barbier, 2001). As such, we know relatively little about the value of many other important marine ecosystem services.

The story is no different in the GBRWHA: here too, most valuation studies have concentrated on a narrow range of benefits (Stoeckl et al., 2011) such as recreation (Carr and Mendelsohn, 2003; Hundloe et al., 1987; Knapman and Stoeckl, 1995; Kragt et al., 2009) or fishing and boating (Farr et al., 2014; Prayaga et al., 2010). More recently, researchers have sought to learn more about some of the region's *non-use values* (Rolfe and Windle, 2012a; Rolfe and Windle, 2012b; Windle and Rolfe, 2005), but significant knowledge gaps remain (see Appendix A). To identify just two important gaps: no information is available on the value of some types of cultural benefits (e.g. aesthetics, spiritual appreciation) or the value of storm protection that the Reef may offer to coastal communities.

Also problematic is the absence of comparative information. No assessments exist that simultaneously value numerous different ecosystem benefits using the same methodological approach. This is a significant knowledge gap because different valuation techniques produce different types of estimates (e.g. marginal prices or expenditures) and may not be comparable or additive. To the best of our knowledge, only one study (Oxford Economics, 2009) has attempted to estimate the TEV of the GBRWHA, by adding the value of different ecosystem services which had been generated from numerous unrelated studies using different methods.

### 2.2. Identification and classification of benefits for assessment

Our research began with an extensive review of the valuation literature relating to the GBRWHA (Appendix A). In addition, we conducted three separate workshops with a variety of stakeholders in Cairns, Townsville, and Brisbane. Participants included representatives from the GBRMPA, Queensland Government, tourism and fishing industries. The aim of these workshops was to learn which of the many ecosystem services provided by the GBRWHA stakeholders thought we should attempt to 'value' and in what managerial and policy context they were operating in. This allowed us to determine what type of information it was most useful to collect (e.g. information about total or marginal values and/or information about particular ecosystem services). Workshop participants were asked to record and priority rank their perceptions of various benefits associated with the GBRWHA to residents of the GBR catchment area; and this information was used to generate a list of benefits for further assessment (hereafter, *community-defined benefits*).

We then conducted a two-way classification of those community defined benefits using both the Common International Classification of Ecosystem services CICES and the TEV; the former shedding light on the core separability question, the latter enabling us to identify benefits that are associated with the market, and thus readily amenable to *valuation*.

### 2.3. Assessing the relative importance of different benefits

As noted earlier, economists have developed many different valuation techniques to monetise a variety of different benefits associated with the environment (see, for example, Bateman et al., 2002; Getzner et al., 2005). Of these, only stated preference approaches are capable of assessing a full range of benefits including non-use values such as existence/bequest values. Although choice modelling and contingent valuation are, arguably, the most popular of these approaches, there is a substantive body of literature on subjective well-being and overall life satisfaction (LS), which offers an alternative way of looking at the 'value' of the environment – a good review can be found in Kristoffersen (2010).

The LS approach to valuation differs from traditional economic valuation methods in one very significant way: traditional approaches assume that utility can only be measured ordinally, whereas LS approaches do not.

Traditional valuation methods do not look for direct and measurable links between ecosystem services and utility. Simplistically, they instead work with indirect utility functions. For example, they may seek to identify, say, two baskets of 'goods' which a person is indifferent between (assume here, that basket A has a $100 lunch at a restaurant with a nice ocean view, whilst basket B has a $300 lunch at a restaurant with no view). They then reason that if a respondent is indifferent between the two baskets, then both baskets must generate the same level of 'utility', these economists can thus use this information to infer that the (lunchtime ocean) view is 'worth' $200 in terms of its ability to generate utility.

In contrast, those working in the LS field ask individuals, directly, to indicate how satisfied they are with their overall quality of life and then use statistical techniques to identify links between various goods (e.g. income, and whether or not the person has a nice view) and stated LS. The questions are asked in very simple terms by, for example, asking respondents to indicate, on a Likert scale, how satisfied they are with their overall quality of life.

Importantly, there is widespread consensus that self-reported measures of LS are valid, replicable, and reliable (Diener, 2009; Silva and Brown, 2013) and researchers have begun to use insights from the LS literature to develop alternative methods for measuring the contribution of the environment to LS. Evidently, there is growing consensus – even within the economics literature – that utility can be measured cardinally (Kristoffersen, 2010), the implication being that one need not always work through indirect utility functions if wishing to assess the value of ecosystem services.

LS studies have been done at both an aggregate level – e.g. using national measures of happiness, indicators of environmental quality and income (Welsch, 2006) – and at an individual level (Frey et al., 2009; MacKerron and Mourato, 2013; Van Praag and Baarsma, 2005). In most cases, researchers have regressed measures of overall quality of life against other potential contributors, to ascertain their relative importance, but others have successfully trialled systems that simply ask people to indicate how important various goods and services are to their overall quality of life and compared ratings (Larson, 2009; Larson et al., 2013). It is that general approach which we used here.

Specifically, we asked people to indicate, on a 5-point Likert scale, how important each of the community defined items selected for assessment were to their overall quality of life. Since respondents have been shown to be highly sensitive to the order in which one presents questions – particularly if asked to evaluate a long list of items (Cai et al., 2011; Lasorsa, 2003) – we produced 24 different versions of the benefits question: all containing the benefits which workshop participants had selected for assessment, but presented in a different order. This information thus provided us with information about the relative importance (to overall quality of life) of a range of different benefits.

### *2.4. Identifying and assessing the relative importance of 'separable' groups of benefits*

As noted in the Section 1 it is only valid to add benefits if they are indeed separable (formally, if they contribute to utility in an additively separable way). Economic theory indicates that three private (and thus non-excludable and non-rivalrous) goods (*x*, *y* and *z*) are additively separable if the quantity of good *x* that an individual is willing to accept as compensation for the loss of good y does not depend upon how much they have of good *z* (i.e., the marginal rate of substitution) (Goldman and Uzawa, 1964). To formally test for this type of separability we would have needed to collect information about the willingness of respondents to 'trade' each community defined item with each other item (153 different pairs in all, potentially giving rise to questionnaire fatigue amongst respondents) (DeShazo and Fermo, 2002; Swait and Adamowicz, 2001). In addition, we would have needed to collect information about the quantity of each item that each respondent 'consumed' – an almost nonsensical task if referring to things such as *preserving the GBRWHA* (a non-rival public good, like many other ecosystem services). So we chose to use two less rigorous approaches when assessing separability – noting that a vitally important area for future research is to develop more appropriate methods of doing so for ecosystem services. Our results and insights are thus indicative; not conclusive, and hereafter we use inverted commas to refer to benefits we have deemed 'separable' to remind readers of that imprecision.

First we examined the correlation between the importance scores assigned to benefits that were directly associated with the market (and thus amenable to direct market valuation). In this case, they were: the jobs and incomes associated with (a) *reef-tourism;* and (*b*) *commercial fishing* and (*c*) *mining and agriculture* (see Tables 1 and 2). Reasoning that the Gross Value of Production (GVP) of these industries is additively separable, we inferred that other pairs of benefits that had lower correlations were also likely 'separable'. Conceivably, those with higher correlations might also be found separable if subjected to more rigorous testing, but we chose to take a conservative approach, treating them as a composite benefit. It is these (composite) benefits which we compared with other benefits to assess the relative contribution of each bundle of benefits to the overall quality of life of residents.

We calculated the importance of each composite benefit as the median of the importance assigned to each benefit, making it possible to compare scores for the entire set of benefits. We performed non-parametric Wilcoxon signed ranks to consider the statistical significance of differences between the importance scores assigned to (composite) benefits.

We also compared the community defined benefit groupings generated by these statistical techniques with the benefit groups associated with both the CICES and the TEV frameworks to assess the overall plausibility of those results.

**Table 1**
Community defined benefits with descriptors used in questionnaire and shortened term used hereafter (in brackets)

| |
|---|
| Benefiting from the jobs and income linked to: |
| the reef-based tourism industry (*reef tourism*) |
| the commercial fishing sector (*commercial fishing*) |
| the mining and agricultural sectors (*mining and agriculture*) |
| Benefiting from low prices associated with cheap shipping transport (*shipping*) |
| Being able to: |
| eat fresh locally caught seafood (*eating seafood*) |
| go fishing, spear-fishing or crabbing (*fishing*) |
| spend time on the beach, go swimming, diving, etc (*beach recreation*) |
| go boating, sailing or jet-skiing (*boating*) |
| Protecting traditional/Indigenous cultural values (*Indigenous culture*) |
| Preserving the GBRWHA either for its own sake or for future generations (*existence/bequest*) |
| "Bragging rights" – being able to say "I live near the Great Barrier Reef" (*bragging rights*) |
| Having: |
| undeveloped and uncrowded beaches and islands (*undeveloped beaches*) |
| beaches and islands without visible rubbish (*no rubbish*) |
| healthy coral reefs *(coral reefs)* |
| healthy reef fish *(reef fish)* |
| healthy habitats for marine plants and animals including whales, dugongs, turtles (*iconic habitats*) |
| clear ocean water with good underwater visibility (*clear ocean water*) |
| healthy mangroves and wetlands that clean polluted water from the land (*mangroves*) |

### *2.5. Drawing inferences about the value of 'separable' groups of benefits and the collective value of all benefits*

In the economics literature, the value of a good is tied to the concepts of compensating and equivalent variation (CV or EV) (Mitchell and Carson, 1989). Formally, CV is the amount of money required to compensate an individual for the loss of a good or service (i.e. to ensure there is no reduction in overall *utility*).

For values closely associated with industry (e.g. the jobs and incomes associated with tourism, commercial fishing, or mining and agriculture), this amount is relatively easy to determine. If an entire industry were to collapse, then residents would need to be compensated for that loss, and the compensation would need to be at least equal to the wages and salaries paid to employees of the industry (a 'worker' focus) and/or those relating to value added (an 'owner' focus). We thus sought information about the wage, salaries, and 'value added' of these industries to determine the 'value' of those (market) benefits.

Lacking comparable information for the community defined benefits which are not associated with the market (hereafter *non-market* benefits), we then assumed that there is a positive relationship between importance and 'value', and used that to draw inferences about the value of the non-market benefits. Specifically, we reasoned that if '*x*' is considered to be more important to overall quality of life then our market benchmark (and if that difference was statistically significant), then '*x*' must have a greater 'value'. As such, our estimates of the value of non-market benefits are relative, not absolute, and whilst we can be confident that one benefit is more or less 'valuable' than our market benchmark, we do not have lower or upper bounds on those estimates.

When assessing the collective value of all (separable) groups of community-defined benefits, we thus assumed that if any group of benefits were deemed to be less important than our market benchmark (MB), then its value was zero (an extremely conservative estimate). If a group of (separable) benefits was deemed more important, then its value was assumed equal to the market benchmark (also conservative) and we counted the number of separable groups (*N*) that were more important than the market benchmark. The collective value of all separable groups of benefits was thus calculated as MB⁎N.

Recognising the sensitivity of this method to the selected MB, we explored differences associated with MBs: reef tourism and mining. Deloitte Access Economics (2013) estimated that the reef based tourism industry contributes a little over \$4 billion per annum to the GBRCA (Deloitte Access Economics, 2013). As discussed in section above, the GVA of mining in this region (\$9.2 billion) greatly exceeds the salaries which those associated with the mining industry who live in this region receive (\$3.2 billion). As such, it seems most appropriate to use \$3 billion as a (very) conservative benchmark 'value' of the mining industry.

**Table 2**
Community defined benefits categorised as types of (a) ecosystem service (using the CICES in columns); and (b) economic 'value' (using the TEV in rows). Benefits with similar text-colour grouped together using various statistical tests (Section 3.4).

| | Provisioning | Regulation and Maintenance | Regulation and Maintenance OR Cultural | Cultural |
|---|---|---|---|---|
| (Market) Use-values | Reef tourism, commercial fishing, mining and agriculture[a] | Shipping | | |
| (Non-market) Use-values | Eating seafood | | | Fishing<br>Beach<br>Boating |
| (Non-market) Use and/or non-use values | | | Undeveloped beaches<br>No rubbish<br>Reefs | <br><br>Indigenous Culture |
| | | | Reef fish<br>Iconic habitat<br>Mangroves<br>Clear ocean water | <br><br>Bragging rights |
| (Non-market) non-use-values | | | | Existence/ bequest |

[a] These benefits are not associated with the ecosystem services of the GBR; rather it is the terrestrial ecosystem which provides them.

To assess the sensitivity of our results to the use of correlation analysis to assess separability, we calculated the TEV following these same steps but using groups of likely separable and inseparable benefits based on a (non-parametric) principal components analysis (see Appendix C).

### 2.6. Data collection and sample overview

For this project, we decided to limit our study to include only those living in the GBRCA (Fig. 1). Accordingly, our findings only reflect the views of these people.

We chose to aim for a geographically stratified random sample using a commercially purchased database, *Australia On Disc*. We selected all names and addresses from the database that had postcodes which lay either partially or entirely within the GBRCA, thus producing our population database.

We then randomly selected 4800 households from the population database, evenly distributed across postcodes, and sent a copy of the survey, with covering letter and information sheet, to each. As noted above, we had 24 different versions of the survey (each version presenting the list of community defined benefits in a different order), so we sent approximately 4 of each of the 24 different versions of the questionnaire to each postcode ensuring proper randomisation. In addition to our benefit/'value' question, the survey included questions about the socio-demographic characteristics of respondents.

Following the Dillman (2007) methodology, we sent a reminder letter with replacement questionnaire to those who had not responded to our first letter, with a third reminder (and replacement questionnaire) after that.

Importantly, some demographic groups (e.g. well educated females) are more likely to respond to mail-out surveys than others (e.g. young males, Indigenous people). Therefore we conducted supplementary face-to-face data collection activities at airports (to capture the views of business people and fly-in-fly out miners who represent an important segment of this population) using the same questionnaire.

## 3. Results

### 3.1. Respondent characteristics

Of the 4800 questionnaires sent out, 823 were returned unopened (incorrect addresses, or recipient having moved away), so we estimate that only 3977 reached their intended recipient. Of these, we received 902 completed questionnaires, giving an overall response rate of 22.7%. This compares favourably with other mail-out response rates encountered in this region (Larson et al., 2013; Zander and Straton, 2010). These extra data collection activities in and around airports, lagoons and beachfronts generated an additional 663 responses, bringing a total number of completed resident questionnaires to 1565.

Our final sample had a good geographic representation compared to the actual distribution of population in this region (Government Statistician, 2013). The sample was also reasonably representative in terms of gender (with 50.3% female respondents) and Indigenous people (6.6% of our sample compared to 7% of the population – Government Statistician, 2013). The sample over-represented those within the 45–64 year age group (45% of sample compared to 32% of population aged $>15$ years), and those with a university degree (31% compared to 16% of the population).

Just over 25% of our respondents noted that the Government, Health or Education sectors were their main source of income: the corresponding figure for the GBRCA population is 29%. Approximately 16% indicated that they were reliant upon the Retail, Accommodation or "Tourism" sectors for employment; compared to 18% recorded in the ABS census (Government Statistician, 2013). Employees of the Mining and Manufacturing sectors were slightly over-represented in our sample comprising almost 20% of respondents (compared to 16% of regional employees); while Agriculture, Fishing and Forestry employees were significantly over-represented: 14% of our sample, compared to 5% of regional employees.

### 3.2. Identification and classification of items for assessment

Our final list of 18 community-defined benefits assessed within the study (with the descriptors that were provided by workshop participants and used within the questionnaires) is given in Table 1.

Table 2 uses both the CICES, shown along the columns, and the TEV framework (rows) to categorise these community defined benefits. Because we chose life satisfaction as the conceptual framework and thus elicited benefits specific to the region through focus groups, many of the descriptors were not readily amenable to classification. This is particularly so for those at the bottom of Table 1, described variously as 'having healthy coral reefs'; 'having healthy reef fish'. The word 'having' is suggestive of existence value (which would seem to indicate that the item should be classified as a cultural service and as a non-use value), but 'having' a healthy reef might be considered important, by respondents, because of the other services a healthy reef provides (which suggests that these benefits might also, or alternatively, be associated with regulating and maintenance services). To address this potential overlap in classification of benefits dependent on respondent interpretation we added an additional column and an additional row for this group of community defined benefits (CICES 'Regulation and Maintenance OR Cultural', TEV 'Use and/or Non-use value').

Although 'water' is considered a provision service under CICES, the community defined descriptor specifies 'clear ocean water with good visibility' – making no reference to provisioning services. We have therefore considered it a descriptor of water condition, and thus categorised it as a regulatory and maintenance service. The benefits of lower prices associated with cheap shipping transport was another item difficult to classify under the CICES (particularly since 'transport services' are excluded – Haines-Young and Potschin, 2013, p. A6). Here, we have considered it a regulating and maintenance service primarily because the GBR provides considerable protection (wave attenuation) for shipping lanes which lay between it and the mainland.

### 3.3. The relative importance of different benefits

Having healthy coral reefs and reef fish, no visible rubbish, iconic habitats, clear ocean water and mangroves, were deemed the most important contributors to overall quality of life – more so than being able to benefit from the jobs and incomes associated with mining, agriculture, commercial fishing or tourism (Fig. 2).

Despite the fact that the Gross Value Added (GVA) associated with the tourism industry is less than that associated with the mining industry in this region, respondents indicated that mining and agriculture benefits were, on average, less important contributors to their overall quality of life than reef tourism benefits. This is not a consequence of sampling problems, since our sample over-represents mining employees (Section 3.1). Neither does it indicate inconsistency in participant responses. Instead, it likely reflects the fact that the mining industry has significantly smaller employment multipliers than the tourism industry (Stoeckl et al., 2013), and in stark contrast to the mining industry, tourism in this part of the world is dominated by micro businesses who are likely to retain surpluses within the region (Tourism Queensland, 2013). As noted above, the total salary spend of mining in this region is only $3.2 billion and thus from the perspective of those living within the GBRCA, the tourism industry, may indeed, contribute more to their overall quality of life than the mining and agriculture industries combined.

### 3.4. Identifying and assessing the relative importance of 'separable' groups of benefits

The highest pair-wise correlation amongst market benefits (assumed to be separable) was between the importance scores assigned to *reef-tourism* and *commercial fishing* (.526 and statistically significant, Appendix B). We thus inferred that other pairs of community-defined benefits that had lower correlations were also likely to be 'separable'; those with higher correlations were considered 'inseparable'.

Fig. 3 provides a conceptual representation of those correlations and associated groupings (see Appendix B for details).

### 3.5. Drawing inferences about the value of 'separable' groups of benefits and the collective value of all benefit

Groupings derived through the analysis of correlation coefficients were used to reduce our original list of 18 community defined benefits to just nine, comprising 7 single benefits, and two 'composites' (Table 3). Differences between the scores associated with Indigenous culture and reef tourism were not statistically significant. Differences between all other (composite) benefits and reef tourism were statistically significant.

Fig. 4 conceptualises our results from the correlation analysis. Benefits receiving the highest mean importance scores are shown as 'higher' in the diagram than others. Arrows show how each (composite) benefit contributes to the overall quality of life of survey respondents. Solid lines relate directly to observations: respondents have told us that these benefits are (variously) important to their overall quality of life. Dotted lines draw attention to the fact that recreation benefits (eating seafood, boating, fishing, beaches), reef tourism, commercial fishing and Indigenous values are sensitive to environmental quality

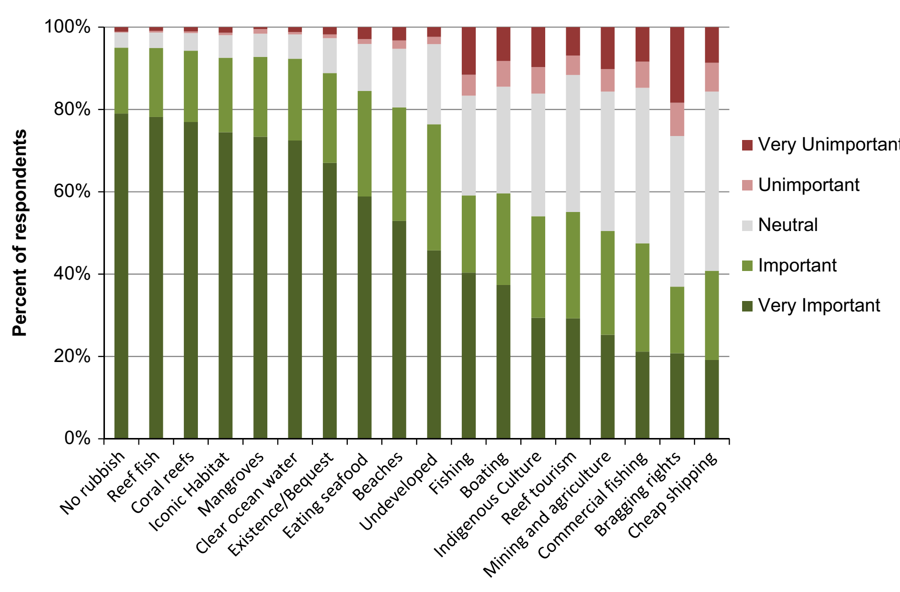


**Fig. 2.** Resident perceptions of the importance of 18 different benefits to their overall quality of life.

(Balkan and Kahn, 1988; Bockstael et al., 1989; Brown and Mendelsohn, 1984; Kragt et al., 2009; Smith et al., 1991).

This suggests that even if *primary* benefits are statistically separable from other benefits, they may not enter the utility function in an additively separable manner. Adding these values in an attempt to generate estimates of TEV would be to run the risk of double counting. Thus, if we use tourism as a MB, we conclude that the total value of all community-defined benefits assessed in this study is likely to exceed $16 billion ($4 billion for each of the items in the shaded section of Table 3, excluding the value of *primary* benefits which amounts to assuming a 100% overlap of values). It may also exceed $20 billion (if there is no overlap).

Using mining as a benchmark, we estimate that the collective value of all ecosystem benefits associated with the GBR that were tested in this study, could exceed $12 billion (excluding mining since it is not a GBR ES and adopting the unlikely assumption that all *primary* benefits overlap with the other benefits), or $15 billion (with no overlap) (Table 4).

Considering the two benchmark values this suggests a potential total economic value for the GBR of $12–$20 billion. This range is somewhat lower to that generated if using PCA to assess separability ($21–$28 billion, see Appendix C).

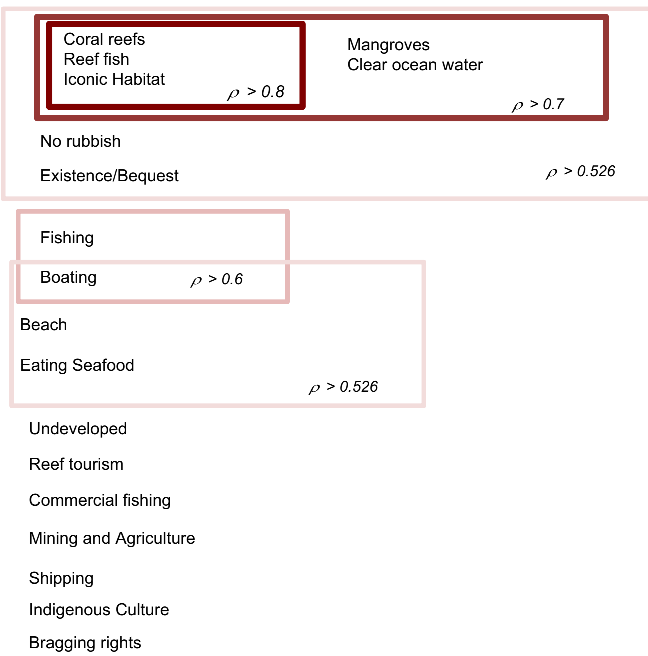


**Fig. 3.** Correlations between the importance scores assigned to different values. If there is a statistically significant correlation between the importance assigned to different benefit (to overall quality of life) and if the correlation coefficient is greater than .526, a box is drawn around the items. The magnitude of the correlation coefficient is shown in the bottom right hand corner. For example, the correlation coefficient between Coral reefs, Reef fish and Iconic Habitats' exceeds .8 and is statistically significant. The importance of those three goods and services is also correlated with Mangroves and Clear Ocean water' – all of those correlations are statistically significant and the coefficients exceed .7. Items without a box are considered 'separable'.

## 4. Discussion

The ranking of community-defined benefits clearly demonstrates that in this region, provisioning services are viewed, by residents, as being less important to overall quality of life than other services. Evidently, job and/or income creating developments that erode the ability of the GBRWHA to provide regulating maintenance or cultural services could be deemed 'uneconomic' (after Daly and Farley, 2004) by residents of the GBRCA in that the extra benefits of having more 'provisions' do not outweigh the loss benefits from other ecosystem services.

Our statistical analysis suggests that 'groupings' of community defined benefits approximately correspond to groupings used in both the CICES and TEV frameworks. The grouping of recreational items such as boating and fishing is unsurprising given that most marine fishing in this region is undertaken from private boats (Blamey and Hundloe, 1993; Fernbach, 2008; GBRMPA, 2003; Innes and Gorman, 2002). The grouping of healthy coral reefs, reef fish, iconic habitats, mangroves, clear water, no rubbish and existence/bequest (hereafter referred to as *primary benefits*) also makes intuitive sense: there is little point in preserving unhealthy reefs and fishes. Moreover, it suggests that respondents associated most of the community defined benefits in the bottom part of Table 1 as different representations of existence values (the word 'having' taking precedence over other descriptors) – indicating that these community defined benefits are most appropriately classified as cultural services within the CICES framework, and as non-use values within the TEV framework.

That said, if one compares these groupings with the classifications from Table 2, it is apparent that one of these groupings traverse those of the CICES. Specifically, some types of cultural services (fishing, boating and beach recreation) are highly correlated with some types of provisioning services (eating seafood). That this seafood issue might arise is pre-empted by Haines-Young and Potschin (2013, p. 22), where the difficulties of dealing with 'extractive' forms of cultural service are discussed. As such, our grouping does not suggest there is a problem with the data or analysis, but may instead indicate a genuine relationship between those benefits.

**Table 3**
Mean importance of each separable group of community defined benefits as a contributor to overall quality of life (using correlation coefficients to group, and reef tourism as the market benchmark).

| Value | Importance | Importance compared to reef-tourism | Inferred value |
|---|---|---|---|
| Coral reefs, reef fish, iconic habitat, mangroves, clear oceans, no rubbish (hereafter, *primary benefits*) | 1.71 | Greater | $4 billion |
| Undeveloped | 1.20 | Greater | $4 billion |
| Eating seafood, fishing, boating, beach (hereafter, *recreation*) | 1.09 | Greater | $4 billion |
| **Reef tourism (market benchmark)** | **.68** | | ≈ **$4** billion |
| Indigenous culture | .61 | Similar | $4 billion |
| Mining and Agriculture | .51 | Less | $0 |
| Commercial fishing | .47 | Less | $0 |
| Shipping | .38 | Less | $0 |
| Bragging rights | .13 | Less | $0 |

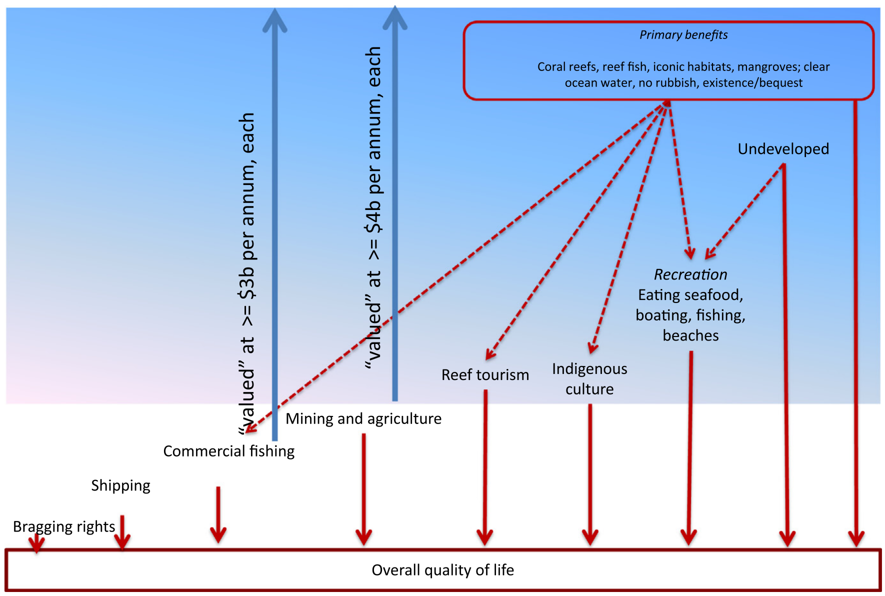


**Fig. 4.** Diagrammatic representation of the way in which various community defined benefits contribute to the overall quality of life of residents in the GBR catchment area – using correlation coefficients to group. The vertical 'height' of each benefit indicates mean importance. Arrows show how benefits contribute to the overall quality of life – directly (solid line from item to quality of life), indirectly (dotted line to another item), or both. Deloitte Access Economics (2013) estimates that the GBR-based tourism industry contributes more than $4 billion per annum to the Great Barrier Reef Catchment Area, so benefits in the top section of the figure are each likely to be 'worth' at least $4 billion per annum. We estimate that the mining sector contributes at least $3 billion per annum to the region in wages, so benefits that are above mining and agriculture are likely to be valued at more than $3 billion.

**Table 4**
Mean importance of each grouped benefit as a contributor to overall quality of life (using correlation coefficients to group, and mining as the market benchmark).

| Benefit | Importance | Importance compared to mining and agriculture | Inferred value |
|---|---|---|---|
| *Primary* benefits | 1.71 | Greater | $3 billion |
| Undeveloped | 1.20 | Greater | $3 billion |
| Recreation | 1.09 | Greater | $3 billion |
| Reef tourism | .68 | Greater | $3 billion |
| Indigenous culture | .61 | Greater | $3 billion |
| **Mining and agriculture (market benchmark)** | **.51** | | **≈ $3 billion** |
| Commercial fishing | .47 | Less | $0 |
| Shipping | .38 | Less | $0 |
| Bragging rights | .13 | Less | $0 |

The conceptualisation presented in Fig. 4 draws attention to the fact that some of the benefits that people derive from GBRWHA-based ecosystem services (e.g. fishing, boating, eating seafood, reef-tourism, commercial fishing, indigenous culture) are contingent upon the existence of a healthy ecosystem. This is analogous to the situation where supporting services are deemed to underlie other ecosystem services (Hein et al., 2006), and has implications relevant to our attempt to draw inferences about the TEV of the GBRWHA. Formally, it means that even if the importance scores assigned to different benefits are not strongly correlated (suggesting that benefits do not overlap), the benefits may still not enter the utility function in an additively separable manner. As such, adding these values in an attempt to generate estimates of TEV would be to run the risk of double counting.

In an extreme situation, double counting could be absolute: the financial worth of the composite good '*primary benefits*' would simply equal the sum of the 'separable' benefits that rely upon it. However, if that were the case, it would suggest that healthy reefs, fish (etc.) only contribute to utility indirectly (e.g. through reef tourism, commercial fishing, recreation and Indigenous culture). As such, one would expect the importance score assigned to *primary benefits* by those who have never been to the GBRWHA, who are not dependent upon either the tourism or the commercial fishing industry for incomes, and who are not Indigenous (hereafter 'reef-independent' people), to be zero.

This was not the case: the importance scores which this subset of respondents (134 in total) assigned to *primary benefits* were lower than the scores assigned by others, but the mean was still 1.51 compared to 1.73 for others. Clearly, the *primary* benefits associated with the GBRWHA are important to the quality of life of 'reef-independent' people: indeed, for this group, *primary* benefits were considered to be the most important benefit in the list. This confirms the findings of other researchers who report significant non-use values associated with the GBRWHA from people living outside the catchment area (Hundloe et al., 1987; Rolfe and Windle, 2012a; Rolfe and Windle, 2012b).

Thus, whilst there is evidence to suggest that our *primary benefits* may overlap other benefits assessed in this study, the overlap is not entire. In fact, the non-overlapping component may be as high as 85% (=1.51/1.73, the *primary benefit score* of non-reef dependent people divided by that of reef-dependent people). Evidently, the collective value of all of the community defined benefits assessed in this study may be closer to our upper-bound estimates (which assume no overlap) than to the lower bound estimates (which assume 100% overlap) – i.e. between $15 billion (if using the mining industry as a benchmark) and $20 billion (if using the tourism industry as a benchmark). This is less than the (no overlap) estimate based on PCA method of grouping benefits ($28 billion, see Appendix C).

We stress the imprecision of these estimates (particularly given the problems of identifying truly separable benefits), but note that they could be conservative. This is because, the benefits considered in this study are not a comprehensive coverage of all ecosystems services provided by the GBRWHA, and we only capture the views of residents. More than 2 million tourists visit the region each year, and they also derive benefit from the region. Similarly the possibly substantial values of people living outside the catchment who are thus neither tourists nor residents (Hundloe et al., 1987; Rolfe and Windle, 2012a, 2012b) have been omitted. In addition, neither residents nor non-residents will perceive the value of the GBR for storm protection, nutrient cycling or other services of which they are largely unaware. These services can be enormous (c.f. Costanza et al., 2008, 2014).

To the best of our knowledge, only one previous study has attempted to estimate the TEV of the GBR (Oxford Economics, 2009), but they did so by adding individual 'values' generated from numerous unrelated studies,. Their estimate of the NPV of the GBR (over a 100 year time horizon, and using a discount rate of 2.65%) was $51 billion; approximately $1.4 billion per annum. Not only is this estimate considerably less than ours, but it is even less than Deloitte Access (2013)'s estimate of the 'value' of just one service – the tourism industry – so may not be a particularly robust estimate to use for comparative purposes. In the absence of other estimates to compare with, we note that the population of Australia is approximately 23 million. At $15–$20 billion, our collective estimate of the value of the GBR thus translates to a value of between $650 and $870 per Australian per annum. This is approximately equal to the amount of money each Australian household spent on tobacco and alcohol during 2009–2010, and considerably less than that spent on income tax ($13,530) or recreation ($8394) (ABS, 2011). Given the significant local, regional and international values associated with the GBR, our estimates do not thus seem widely implausible.

Also to the best of our knowledge, no previous study has generated financial estimates of the value of having undeveloped and uncrowded beaches and islands, or of protecting Indigenous cultural values in this region or elsewhere, so we have no external reference with which to judge the plausibility of those estimates. As regards our *primary* values, Rolfe and Windle (2012a, 2012b) used choice modelling to consider a range of other closely associated values, but this technique generates estimates of marginal values so are not comparable with ours. Hundloe et al. (1987) used contingent valuation to estimate non-use values of the GBR for Australian residents ($45 million in 1987 dollars, or about $110 million in today's currency). Our estimates are considerably higher, possibly reflecting more social recognition of the iconic status of the GBRWHA, but also likely to be attributable to the numerous methodological differences between the two studies, including, but not limited to, factors such as strategic bias (for contingent valuation studies). While many previous researchers have assessed tourism and recreation values in the GBR, most have focused on expenditure/regional impact or on consumer surplus, so here too, results are not comparable to ours (see Appendix A).

## 5. Concluding comments

Estimating the TEV of entire ecosystems is difficult. In this paper, we have trialled a new method for assessing the total economic value of a large and complex ecosystem – using the Great Barrier Reef World Heritage Area (GBRWHA) as an example. We have found that provisioning services associated with the GBRWHA are considered, by residents of the catchment, to be less important to their overall quality of life than other ecosystem services. Moreover, it seems that the collective 'value' of the broad range of ecosystem services considered in this study is likely to be in the range of $15–$20 billion per annum – perhaps substantially more.

We have also found evidence to suggest that some ecosystem services – termed here *primary* benefits, but closely associated with what economists would term non-use values – may be inseparable from (or 'overlap' with) other benefits. Analogous to the situation where supporting services are deemed to underlie other ecosystem services, it seems that residents recognise that having a healthy ecosystem is important by and of itself, but it is also a precondition for being able to use the ecosystem for recreation and/or livelihoods. This has important implications for those conducting valuation studies since it suggests that at least some portion of non-use values may 'overlap' use values – formally, they may not enter the utility function in an additively separable way. Clearly if these values are inseparable, partial equilibrium assessments of 'value' will be misleading (Hanemann and Morey, 1992). The approach we have taken to identify and control for this problem is far from perfect; but it does provide one way of trying to get around this issue. More rigorous methods are needed and could perhaps use nested utility functions such as those used by Carbone and Smith (2013). But we note that empirical researchers may be significantly limited in what they can do by data constraints: current methods of formally testing for separability (like those commonly adopted by researchers working with systems of market demand equations) require price and quantity observations for all tested goods. Entirely new methods may thus be required since many ecosystem services are non-rival, non-excludable public goods and an individual utility approach to assessing their separability and their contributions to sustainable human well-being may be inappropriate to start with. There is clearly much work to be done on this challenging and important problem.

## Acknowledgements

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## Appendix A

See Table A1.

## Appendix B

See Table B1.

## Appendix C

To assess the robustness of our TEV estimates to the methodological approach of assessing separability, we conducted the same analysis as presented in the main text using (non-parametric) principal components analysis.

### *C.1. Using PCA to identify separable groups*

Using Principal Components Analysis (PCA), our importance scores for the 18 benefits assessed in the questionnaire collapsed into 5 factors presented in Table C1. The benefits that load onto the first factor include all of those which grouped together using correlation coefficients, and also undeveloped beaches (see Larson et al. (2014) for more detailed analysis). We have thus re-named

**Table A1**
Valuation studies in and around the GBRWHA. Applicable to the general GBR catchment area unless otherwise stated (caution: general catchment area is not always the same geographic region across studies).

| Good(s) or service(s) | Estimate | Type of estimate |
|---|---|---|
| Cognitive/Scientific Research | 1987 – Direct and indirect impact (Driml, 1987, using IO)<br>$ 6.9 million<br>1994 – Direct and indirect impact (Driml, 1994, using IO)<br>$ 19 million | Financial impact and/or expenditure |
| Tourism and/or recreation | 1987 – Direct and indirect impact (Driml, 1987 using IO analysis)<br>$45.9 million (Island resorts)<br>$ 1.6 million (Island camping)<br>$159–$272 million (1981/82 $AUD)<br>1994 – Direct and indirect impact (Driml, 1994, using IO)<br>$ 682 million per annum (Tourism);<br>$ 923 million per annum (all reef-based recreation)<br>1995 – Direct and indirect impact (Driml and Common, 1995, using change in productivity)<br>$477–$682 million<br>1996 – Gross financial value (Driml, 1999 using change in productivity)<br>$759 million<br>2005 – Direct and indirect impacts (Access Economics, 2005) using IO analysis of "economic contribution"<br>$3.1 billion in 2003<br>2008 9 – Value added (Access Economics, 2008) using IO analysis of "economic contribution"<br>$61 million in 2006–2007<br>2010 – Direct and indirect impact of live-aboard dive boats in Cairns/Port Douglas region (Stoeckl et al., 2010, using IO analysis)<br>$16 million per annum (Cairns/Port Douglas region) | Financial impact and/or expenditure |
| Tourism and/or recreation | 1995 – Consumer surplus (Knapman and Stoeckl, 1995, using Travel Cost Analysis)<br>$3–$13 million per annum (Hinchinbrook Island)<br>2003 – Recreation use value (Carr and Mendelsohn, 2003, using Travel Cost Approach)<br>USD $700 million – $1.6 billion per annum;<br>USD $400 million (domestic tourism only)<br>2009 – Consumer surplus (Kragt et al., 2009, using Contingent Behaviour Model)<br>$185 for an average diver/snokeller per trip<br>$48 million (annual CS for reef visitors – Port Douglas only)<br>2011 – Consumer surplus (Rolfe et al., 2011, using Travel Cost Analysis)<br>$35 per person per trip per day (Beaches)<br>$331 per person per trip per day (Islands)<br>$183 per person per trip per day (Recreational fishing, boating, and sailing) | Consumer surplus |
| Beach recreation | 2012 – Value of a single beach visit (Rolfe and Gregg, 2012, using the travel cost model)<br>$35.09 per visit<br>$587.3 million per annum | Consumer surplus |
| Beach recreation | 2012 – Loss of recreational value as a result of a decline in water quality (Rolfe and Gregg, 2012, using contingent behaviour models)<br>$1.30 per trip with 1% decline in water quality | Marginal value (Willingness to Pay – WTP, or Willingness to Accept – WTA) |
| Fishing and/or boating | 1987 – Financial impact (Driml, 1987 using IO)<br>$25.5 million (charter boats)<br>$36.3 million (commercial fishing)<br>$42.8 million (recreational fishing)<br>1993– Landed value of three major commercial prawn species (*Penaeus esculentus, P. semisulcatus* and *Metapenaeus endeavouri*) (Watson et al., 1993, using a deterministic simulation model)<br>$1.2 million per annum (range $.6–$2.2 million)<br>1994 – Direct (and indirect) output (Driml, 1994 using IO)<br>$128 million (commercial fishing )<br>$94 million (recreational fishing and boating )<br>2000 – Gross financial value (KPMG, 2000 using change in productivity)<br>$112 million in 1993–1994 to<br>$107 million 1997–1999<br>2002– Value of capital equipment (Murphy 2002a, 2002b, using expenditure surveys)<br>$152.2 million capital equipment (Mackay/Whitsunday region)<br>$167.9 million capital equipment (Townsville region)<br>2002b – Expenditure (Murphy 2002a, 2002b, using expenditure surveys)<br>$42.62 million per annum expenditure (Mackay/Whitsunday region)<br>$69.85 million per annum expenditure (Townsville region)<br>2003 – Gross value (Productivity Commission, 2003 [4] using gross value of production)<br>$240 million (recreational fishing)<br>$119 million (commercial fishing)<br>2005 – Direct and indirect value added (Access Economics, 2005, using IO analysis to estimate economic 'contribution') | Financial impact and/or expenditure |

**Table A1** (*continued* )

| Good(s) or service(s) | Estimate | Type of estimate |
|---|---|---|
| | $104 million (commercial fishing)<br>$409 million (recreational fishing and boating)<br>2008 – Direct and indirect value added (Access Economics, 2008, using IO analysis to estimate economic 'contribution'<br>$39 million (rRecreational fishing )<br>$28 million ( recreational fishing ) | |
| Fishing and/or boating | 1991 –Willingness to pay for fishing for one year (or accept compensation for loss) (Blamey and Hundloe, 1993, using Contingent Valuation for the GBR region recreational fishes only)<br>$15,500 per annum, using Mean WTA<br>$4900 per annum, using Median WTA<br>$2020 per annum, using Mean WTP<br>$832 per annum year, using Median WTP<br>2006 – Reduction in spending on recreational fishing given reduction in water quality (Alam et al., 2006, using the SedNet model)<br>$1.5 million per annum (recreational fishing)<br>2006 – Reduction in value of catch given reduction in water quality (Alam et al., 2006, using the SedNet model)<br>$53 million per annum (commercial fishing)<br>2006 – Reduction in Value of aquaculture given reduction in water quality (Alam et al., 2006, using the SedNet model)<br>$16.2 million | Marginal value (Willingness to Pay – WTP, or Willingness to Accept – WTA) |
| General assessments of "Environmental Health" or improvements in "Environmental health" | 2005 – Willingness to pay for a 1% improvement in the environmental health of the Fitzroy estuary (Windle and Rolfe, 2005, using choice modelling)<br>$3.21 per year per household)<br>2009 – Net Present Value of the cost of Coral Bleaching (Oxford economics 2009, adding variety of estimates from published studies under TEV framework, with discount rate of 2.65%)<br>$37.7 billion (GBR)<br>$16.3 billion (Cairns area)<br>$1.08 billion per annum over the course of a century (GBR)<br>2012 WTP to protect Reef (Rolfe and Windle, 2012a using choice modelling)<br>$12.72 (Cairns) per household per annum<br>$11.75 (Townsville) per household per annum<br>$8.06 (Capricorn coast) per household per annum<br>2012 WTP to protect Fish (Rolfe and Windle, 2012a using choice modelling)<br>$16.33 (Cairns) per household per annum<br>$11.89 (Townsville) per household per annum<br>$13.36 (Capricorn coast) per household per annum<br>2012 WTP to protect Seagrass(Rolfe and Windle, 2012a using choice modelling)<br>$10.53 (Cairns) per household per annum<br>$6.88 (Townsville) per household per annum<br>$8.36 (Capricorn coast) per household per annum<br>2012 WTP to protect the GBR (Rolfe and Windle, 2012a using choice modelling)<br>$21.68 per household per annum for 5 years | Marginal value (Willingness to Pay – WTP, or Willingness to Accept – WTA) |
| Improvements in water quality | 2011 – Cost of reductions in nitrogen use (Rolfe and Windle, 2011, using field trials and water quality tenders and trading mechanisms to reveal opportunity costs)<br>$446,000 per annum or $4.56 p/kg of reduction (Burdekin, sugarcane)<br>$200,000 per annum or $.44 p/kg (Burnett-Mary, dairy)<br>2011 – Cost of reductions in phosphorus use (Rolfe and Windle, 2011, using field trials and water quality tenders and trading mechanisms to reveal opportunity costs<br>$2.40 p/kg reduced (Burnett-Mary, dairy )<br>$10.80 p/kg reduced (Mackay/Whitsunday-cane sector)<br>2011 – Cost of reductions in pesticide use (Rolfe and Windle, 2011, using field trials and water quality tenders and trading mechanisms to reveal opportunity costs)<br>$94,000 at an average cost of $16.90 per/kg (Burdekin cane and grazing tender) | Financial impact and/or expenditure |
| Non-use values | 1987 – Non-use values for the GBR (Australian population) – (Hundloe et al., 1987, using the contingent valuation approach)<br>$45 million per annum | Total value |
| TEV as the sum of individual components | 2009 – Net Present Value of the Reef (Oxford economics 2009, adding variety of estimates from published studies under TEV framework, with discount rate of 2.65%)<br>$51.4 billion (GBR)<br>$17.9 billion (Cairns area) | Total and marginal value |

**Table B1**
Correlations between the importance respondents attributed to different 'values'.

| | | Tourism | Commercial fishing | Mining and agriculture | Cheap Shipping | Seafood | Fishing | Time on beaches | Boating | Indigenous Culture | Preserving for future generations | Bragging rights | Undeveloped beaches | Lack of Visible Rubbish | Healthy coral reefs | Healthy reef fish | Iconic Marine Mammals | Clear Oceans | Mangroves |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tourism | Correlation Coefficient | 1.000 | .526** | .241** | .337** | .258** | .219** | .289** | .259** | .210** | .257** | .233** | .168** | .197** | .269** | .262** | .277** | .261** | .235** |
| | Sig. (2-tailed) | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1461 | 1437 | 1430 | 1371 | 1451 | 1420 | 1439 | 1427 | 1436 | 1450 | 1439 | 1428 | 1448 | 1452 | 1448 | 1448 | 1447 | 1447 |
| Commercial fishing | Correlation Coefficient | .526** | 1.000 | .428** | .382** | .312** | .238** | .184** | .198** | .110** | .127** | .146** | .098** | .098** | .140** | .166** | .151** | .150** | .153** |
| | Sig. (2-tailed) | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1437 | 1464 | 1435 | 1380 | 1455 | 1421 | 1438 | 1430 | 1440 | 1452 | 1439 | 1432 | 1452 | 1455 | 1451 | 1452 | 1451 | 1450 |
| Mining and agriculture | Correlation Coefficient | .241** | .428** | 1.000 | .467** | .187** | .174** | .114** | .154** | .015 | .050* | .079** | -.022 | .030 | .044 | .064** | .062** | .053* | .036 |
| | Sig. (2-tailed) | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .482 | .031 | .000 | .330 | .202 | .060 | .006 | .008 | .022 | .121 |
| | N | 1430 | 1435 | 1456 | 1382 | 1447 | 1419 | 1433 | 1425 | 1434 | 1446 | 1435 | 1427 | 1445 | 1450 | 1446 | 1448 | 1446 | 1446 |
| Cheap Shipping | Correlation Coefficient | .337** | .382** | .467** | 1.000 | .196** | .155** | .135** | .172** | .085** | .077** | .141** | .043 | .055* | .069** | .073** | .087** | .086** | .079** |
| | Sig. (2-tailed) | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .001 | .000 | .063 | .021 | .004 | .003 | .000 | .000 | .001 |
| | N | 1371 | 1380 | 1382 | 1400 | 1392 | 1365 | 1380 | 1372 | 1377 | 1389 | 1379 | 1370 | 1388 | 1392 | 1390 | 1391 | 1390 | 1390 |
| Seafood | Correlation Coefficient | .258** | .312** | .187** | .196** | 1.000 | .566** | .426** | .385** | .101** | .233** | .194** | .217** | .248** | .293** | .321** | .262** | .287** | .308** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1451 | 1455 | 1447 | 1392 | 1513 | 1463 | 1488 | 1474 | 1484 | 1502 | 1487 | 1478 | 1502 | 1507 | 1503 | 1503 | 1502 | 1501 |
| Fishing | Correlation Coefficient | .219** | .238** | .174** | .155** | .566** | 1.000 | .439** | .634** | .033 | .101** | .183** | .135** | .152** | .176** | .199** | .182** | .182** | .199** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .129 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1420 | 1421 | 1419 | 1365 | 1463 | 1465 | 1452 | 1447 | 1439 | 1456 | 1445 | 1437 | 1455 | 1460 | 1456 | 1456 | 1454 | 1453 |

| | | Tourism | Commercial fishing | Mining and agriculture | Cheap Shipping | Seafood | Fishing | Time on beaches | Boating | Indigenous Culture | Preserving for future generations | Bragging rights | Undeveloped beaches | Lack of Visible Rubbish | Healthy coral reefs | Healthy reef fish | Iconic Marine Mammals | Clear Oceans | Mangroves |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time on beaches | Correlation Coefficient | .289** | .184** | .114** | .135** | .426** | .439** | 1.000 | .528** | .183** | .308** | .237** | .342** | .325** | .380** | .375** | .366** | .364** | .365** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1439 | 1438 | 1433 | 1380 | 1488 | 1452 | 1491 | 1465 | 1466 | 1482 | 1469 | 1462 | 1482 | 1487 | 1483 | 1482 | 1481 | 1480 |
| Boating | Correlation Coefficient | .259** | .198** | .154** | .172** | .385** | .634** | .528** | 1.00 | .112** | .140** | .262** | .199** | .193** | .207** | .217** | .219** | .223** | .220** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1427 | 1430 | 1425 | 1372 | 1474 | 1447 | 1465 | 1478 | 1452 | 1468 | 1456 | 1449 | 1468 | 1472 | 1468 | 1469 | 1468 | 1466 |
| Indigenous Culture | Correlation Coefficient | .210** | .110** | .015 | .085** | .101** | .033 | .183** | .112** | 1.00 | .380** | .257** | .247** | .235** | .312** | .280** | .314** | .308** | .318** |
| | Sig. (2-tailed) | .000 | .000 | .482 | .000 | .000 | .129 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1436 | 1440 | 1434 | 1377 | 1484 | 1439 | 1466 | 1452 | 1492 | 1484 | 1473 | 1457 | 1479 | 1485 | 1481 | 1481 | 1480 | 1479 |
| Preserving for future generations | Correlation Coefficient | .257** | .127** | .050* | .077** | .233** | .101** | .308** | .140** | .380** | 1.000 | .228** | .379** | .460** | .574** | .541** | .565** | .542** | .551** |
| | Sig. (2-tailed) | .000 | .000 | .031 | .001 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1450 | 1452 | 1446 | 1389 | 1502 | 1456 | 1482 | 1468 | 1484 | 1509 | 1487 | 1475 | 1498 | 1504 | 1500 | 1499 | 1499 | 1498 |
| Bragging rights | Correlation Coefficient | .233** | .146** | .079** | .141** | .194** | .183** | .237** | .262** | .257** | .228** | 1.00 | .213** | .163** | .216** | .196** | .221** | .257** | .218** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1439 | 1439 | 1435 | 1379 | 1487 | 1445 | 1469 | 1456 | 1473 | 1487 | 1494 | 1460 | 1483 | 1487 | 1483 | 1483 | 1483 | 1482 |
| Undeveloped beaches | Correlation Coefficient | .168** | .098** | -.022 | .043 | .217** | .135** | .342** | .199** | .247** | .379** | .213** | 1.00 | .433** | .424** | .421** | .408** | .406** | .438** |
| | Sig. (2-tailed) | .000 | .000 | .330 | .063 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 1428 | 1432 | 1427 | 1370 | 1478 | 1437 | 1462 | 1449 | 1457 | 1475 | 1460 | 1485 | 1479 | 1480 | 1477 | 1478 | 1476 | 1475 |
| Lack of Visible Rubbish | Correlation Coefficient | .197** | .098** | .030 | .055* | .248** | .152** | .325** | .193** | .235** | .460** | .163** | .433** | 1.00 | .689** | .681** | .631** | .588** | .592** |
| | Sig. (2-tailed) | .000 | .000 | .202 | .021 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 | .000 |
| | N | 1448 | 1452 | 1445 | 1388 | 1502 | 1455 | 1482 | 1468 | 1479 | 1498 | 1483 | 1479 | 1509 | 1505 | 1501 | 1501 | 1501 | 1499 |

| | | Tourism | Commercial fishing | Mining and agriculture | Cheap Shipping | Seafood | Fishing | Time on beaches | Boating | Indigenous Culture | Preserving for future generations | Bragging rights | Undeveloped beaches | Lack of Visible Rubbish | Healthy coral reefs | Healthy reef fish | Iconic Marine Mammals | Clear Oceans | Mangroves |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Healthy coral reefs | Correlation Coefficient | .269$^{**}$ | .140$^{**}$ | .044 | .069$^{**}$ | .293$^{**}$ | .176$^{**}$ | .380$^{**}$ | .207$^{**}$ | .312$^{**}$ | .574$^{**}$ | .216$^{**}$ | .424$^{**}$ | .689$^{**}$ | 1.000 | .892$^{**}$ | .801$^{**}$ | .731$^{**}$ | .738$^{**}$ |
| | Sig. (2-tailed) | .000 | .000 | .060 | .004 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 | .000 |
| | N | 1452 | 1455 | 1450 | 1392 | 1507 | 1460 | 1487 | 1472 | 1485 | 1504 | 1487 | 1480 | 1505 | 1515 | 1508 | 1507 | 1505 | 1504 |
| Healthy reef fish | Correlation Coefficient | .262$^{**}$ | .166$^{**}$ | .064$^{**}$ | .073$^{**}$ | .321$^{**}$ | .199$^{**}$ | .375$^{**}$ | .217$^{**}$ | .280$^{**}$ | .541$^{**}$ | .196$^{**}$ | .421$^{**}$ | .681$^{**}$ | .892$^{**}$ | 1.000 | .786$^{**}$ | .730$^{**}$ | .745$^{**}$ |
| | Sig. (2-tailed) | .000 | .000 | .006 | .003 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 | .000 |
| | N | 1448 | 1451 | 1446 | 1390 | 1503 | 1456 | 1483 | 1468 | 1481 | 1500 | 1483 | 1477 | 1501 | 1508 | 1511 | 1504 | 1503 | 1502 |
| Iconic Marine Mammals | Correlation Coefficient | .277$^{**}$ | .151$^{**}$ | .062$^{**}$ | .087$^{**}$ | .262$^{**}$ | .182$^{**}$ | .366$^{**}$ | .219$^{**}$ | .314$^{**}$ | .565$^{**}$ | .221$^{**}$ | .408$^{**}$ | .631$^{**}$ | .801$^{**}$ | .786$^{**}$ | 1.000 | .743$^{**}$ | .732$^{**}$ |
| | Sig. (2-tailed) | .000 | .000 | .008 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 | .000 |
| | N | 1448 | 1452 | 1448 | 1391 | 1503 | 1456 | 1482 | 1469 | 1481 | 1499 | 1483 | 1478 | 1501 | 1507 | 1504 | 1511 | 1504 | 1502 |
| Clear Oceans | Correlation Coefficient | .261$^{**}$ | .150$^{**}$ | .053$^{*}$ | .086$^{**}$ | .287$^{**}$ | .182$^{**}$ | .364$^{**}$ | .223$^{**}$ | .308$^{**}$ | .542$^{**}$ | .257$^{**}$ | .406$^{**}$ | .588$^{**}$ | .731$^{**}$ | .730$^{**}$ | .743$^{**}$ | 1.000 | .763$^{**}$ |
| | Sig. (2-tailed) | .000 | .000 | .022 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | .000 |
| | N | 1447 | 1451 | 1446 | 1390 | 1502 | 1454 | 1481 | 1468 | 1480 | 1499 | 1483 | 1476 | 1501 | 1505 | 1503 | 1504 | 1510 | 1504 |
| Mangroves | Correlation Coefficient | .235$^{**}$ | .153$^{**}$ | .036 | .079$^{**}$ | .308$^{**}$ | .199$^{**}$ | .365$^{**}$ | .220$^{**}$ | .318$^{**}$ | .551$^{**}$ | .218$^{**}$ | .438$^{**}$ | .592$^{**}$ | .738$^{**}$ | .745$^{**}$ | .732$^{**}$ | .763$^{**}$ | 1.00 |
| | Sig. (2-tailed) | .000 | .000 | .121 | .001 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | |
| | N | 1447 | 1450 | 1446 | 1390 | 1501 | 1453 | 1480 | 1466 | 1479 | 1498 | 1482 | 1475 | 1499 | 1504 | 1502 | 1502 | 1504 | 1509 |

**Table C1**
Results of PCA analysis. Benefits which group together using PCA, with factor loadings in brackets; adapted from Larson et al. (2014).

| Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 |
|---|---|---|---|---|
| Coral reefs (.922)<br>Reef fish (.908)<br>Iconic habitats (.885)<br>Mangroves (.836)<br>Clear ocean water (.801)<br>No rubbish (.727)<br>Existence/bequest (.655)<br>Undeveloped (.501) | Fishing (.855)<br>Boating (.831)<br>Beach (.686)<br>Eating Seafood (.629) | Mining and agriculture (.815)<br>Shipping (.768)<br>Commercial fishing (.758)<br>Reef tourism (.576) | Indigenous culture (.745) | Bragging rights (.739) |

**Table C2**
Mean importance of each group of community-defined benefits to overall quality of life (using PCA to group; and the value of the tourism industry + the value of wages paid in the mining industry as the benchmark 'value').

| Value | Importance | Importance compared to industry | Inferred financial 'worth' |
|---|---|---|---|
| *Primary* benefits + undeveloped | 1.70 | Greater | $7 billion |
| Recreation | 1.09 | Greater | $7 billion |
| Indigenous culture | .61 | Greater | $7 billion |
| **Reef tourism and mining**[a] **(market benchmark)** | **.50** | | **$7** billion |
| Bragging rights | .13 | Less | $0 |

[a] Group also includes agriculture, commercial fishing and cheap shipping, but these 'values' are not included in the estimated market benchmark.

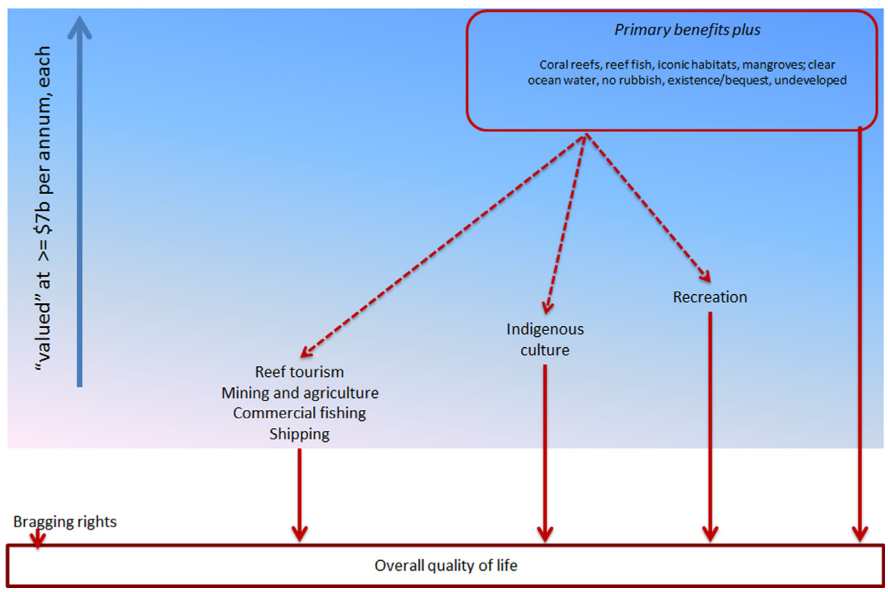


**Fig. C1.** Diagrammatic representation of the way in which various community defined benefits contribute to the overall quality of life of residents in the GBR catchment area – using PCA to group. The vertical 'height' of each benefit indicates mean importance. Arrows show how values contribute to the overall quality of life – directly (solid line from item to quality of life), indirectly (dotted line to another item), or both. Deloitte Access Economics (2013) estimates that the GBR-based tourism industry contributes more than $4 billion per annum to the Great Barrier Reef Catchment Area; mining contributes at least $3 billion in salaries (Rolfe et al., 2011), so benefits in the top section of the figure are each likely to be 'worth' at least $7 billion per annum..

this group 'primary plus', noting that this alternate grouping lends similar insights to those discussed in the main body of the paper. Also similar to the correlation approach is the fact that Indigenous culture and 'bragging' rights are clearly separable, although all industry benefits group together.

Groupings derived through the PCA analysis reduced the original list of 18 community-defined benefits to six, with all industry benefits grouping together. Following the methods used for the correlation analysis, we calculated the importance of each composite benefit as the median of the importance assigned to each benefit, making it possible to compare scores for the entire set of benefits (Table C2). We were unable to find recent estimates of either the salaries or the GVP associated with the agriculture industry for the GBR catchment (such data is generally only available at the state level); neither were data available about the value of cheap shipping. The GVP associated with the commercial fishing industry in this region is estimated at less than $200 million (Deloitte Access Economics, 2013). So we chose to conservatively focus on only the value of the tourism industry (≈ $4 billion) and the salaries associated with the mining industry (≈ $3 billion), giving an 'industry' market benchmark value of at least $7 billion.

Using this benchmark, the collective value of ecosystem benefits provided by the GBR can be estimated as between $21 billion ($7 billion for each of the values deemed more important than industry, plus the $7 billion from industry), if all *primary*-plus benefits are assumed to overlap with other benefits, and $28 billion (if no overlap) – see Table C2 and Fig. C1.

## References


Access Economics, 2005. Measuring the Economic and Financial Value of the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, Townsville, Qld.

Access Economics, 2008. Economic Contribution to the GBRMP, 2006–2007. Great Barrier Reef Marine Park Authority, Townsville, Qld.

Alam, K., Rolfe, J., Donaghy, P., 2006. Economic and social impact assessment of water quality improvement. Australas. J. Reg. Stud. 12 (1), 85–102.

Alder, M.D., Posner, E.A., 1999. Rethinking cost–benefit analysis. Yale Law J. 109, 165–247.

Balkan, E., Kahn, J.R., 1988. The value of changes in deer hunting quality: a travel cost approach. Appl. Econ. 204, 533–539. http://dx.doi.org/10.1080/00036848800000062.

Balmford, A., Fisher, B., Green, R.E., Naidoo, R., Strassburg, B., Turner, K., Rodrigues, A., 2011. Bringing ecosystem services into the real world: an operational framework for assessing the economic consequences of losing wild nature. Environ. Resourc. Econ. 482, 161–175. http://dx.doi.org/10.1007/s10640-010-9413-2.

Bateman, I., Carson, R.J., Day, B., Hanemann, M., Hanleys, N., Hett, T., Swanson, J., 2002. Economic Valuation with Stated Preference Technique: A Manual. Edward Elgar, Cheltenham.

Birol, E., Cox, V., 2007. Using choice experiments to design wetland management programmes: the case of Severn Estuary Wetland, UK. J. Environm. Plan. Manag. 503, 363–380.

Blamey, R.K., Hundloe, T.K., 1993. Characteristics of Recreational Boat Fishing in the Great Barrier Reef Region. A Report to the Great Barrier Reef Marine Park. Authority, Townsville, Qld.

Bockstael, N.E., McConnell, K.E., Strand, I.E., 1989. Measuring the benefits of improvements in water quality: the Chesapeake Bay. Mar. Resourc. Econ. 61, 1–18.

Brander, L.M., Van Beukering, P., Cesar, H., 2007. The recreational value of coral reefs: a meta-analysis. Ecol. Econ. 631, 209–218.

Breaux, A., Farber, S., Day, J., 1995. Using natural coastal wetlands systems for wastewater treatment: an economic benefit analysis. J. Environ. Manag. 443, 285–291.

Brodie, J., 2014. Dredging the Great Barrier Reef: use and misuse of science. Estuar. Coast. Shelf Sci. 142, 1–3.

Brodie, J.E., Kroon, F.J., Schaffelke, B., Wolanski, E.C., Lewis, S.E., Devlin, M.J., Davis, A. M., 2012. Terrestrial pollutant runoff to the Great Barrier Reef: an update of issues, priorities and management responses. Mar. Pollut. Bull. 654-9, 81–100.

Brown Jr., G., Mendelsohn, R., 1984. The Hedonic Travel Cost Method. Rev. Econ. Stat. 663, 427–433. http://dx.doi.org/10.2307/1924998.

Cai, B., Cameron, T., Gerdes, G.R., 2011. Distal order effects in stated preference surveys. Ecol. Econ. 706, 1101–1108.

Carbone, J., Smith, V.K., 2013. Valuing nature in general equilibrium. J. Environ. Econ. Manag. 66, 72–89.

Carr, L., Mendelsohn, R., 2003. Valuing coral reefs: a travel cost analysis of the Great Barrier Reef. AMBIO: J. Hum. Environ. 325, 353–357.

Costanza, R., Farber, S.C., Maxwell, J., 1989. Valuation and management of wetlands ecosystems. Ecol. Econ. 1, 335–361.

Costanza, R., 2000. Social goals and the valuation of ecosystem services. Ecosystems 3, 4–10.

Costanza, R., dArge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Costanza, R., Pérez-Maqueo, O., Martinez, M.L., Sutton, P., Anderson, S.J., Mulder, K., 2008. The value of coastal wetlands for hurricane protection. Ambio 374, 241–248. http://dx.doi.org/10.2307/25547893.

Costanza, R., Kubiszewski, I., Ervin, D., Bluffstone, R., Boyd, J., Brown, D., Chang, H., Dujon, V., Granek, E., Polasky, S., Shandas, V., Yeakley, A. (2011) Valuing Ecological Systems and Services. F1000 Biology Reports 3, p. 14.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Global Environ. Change 26, 152–158.

Daly, H.E., Farley, J., 2004. Ecological Economics: Principles and Applications. Island Press, Washington.

De Groot, R.S., Matthew, A.W., Roelof, M.J.B., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 413, 393–408.

De'ath, G., Fabricius, K.E., Sweatman, H., Puotinen, M., 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proc. Natl. Acad. Sci. 10944, 17995–17999.

Delisle, A., 2012. A Socio-Economic Investigation of the Torres Strait Indigenous Dugong and Turtle Fisheries (Unpublished Ph.D. thesis). James Cook University, Townsville, Australia.

Deloitte Access Economics, 2013. Economic Contribution of the Great Barrier Reef. Great Barrier Reef Marine Park Authority, Townsville.

DeShazo, J.R., Fermo, G., 2002. Designing choice sets for stated preference methods: the effects of complexity on choice consistency. J. Environ. Econ. Manag. 441, 123–143.

Diener, E., 2009. The Science of Well-Being: The Collected Works of Ed Diener, vol. 1. Springer.

Dillman, D.A., 2007. Mail and Internet Surveys: the Tailored Design Method. John Wiley & Sons, Inc., San Francisco.

Driml, S., 1987. Economic Impacts of Activities on the Great Barrier Reef, Townsville.

Driml, S., 1994. Protection for profit: economic and financial values of the Great Barrier Reef World Heritage Area and other protected areas. Great Barrier Reef Marine Park Authority.

Driml, S., 1999. Dollar values and trends of major direct uses of the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority.

Driml, S., Common, M., 1995. Economic and financial benefits of tourism in major protected areas. Austr. J. Environ. Manag. 21, 19–29.

Elger, T., Jones, B.E., 2008. Can rejections of weak separability be attributed to random measurement errors in the data? Econ. Lett. 991, 44–47.

Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Ecol. Econ. 41, 375–392.

Fabricius, K.E., De'ath, G., Humphrey, C., Zagorskis, I., Schaffelke, B., 2013. Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. Estuar. Coast. Shelf Sci. 116, 57–65.

Farr, M., Stoeckl, N., Sutton, S., 2014. Recreational fishing and boating: are the determinants the same? Mar. Policy 47, 126–137.

Fernbach, M., 2008. A review of recreational activities undertaken in the Great Barrier Reef Marine Park recreation review stage 1. Great Barrier Reef Marine Park Authority.

Fisher, B., Turner, K., 2008. Ecosystem services: classification for valuation. Biol. Conserv. 1415, 1167–1169.

Frey, B.S., Simon, L., Stutzer, A., 2009. The life satisfaction approach to valuing public goods: the case of terrorism. Public Choice 1383 (4), 317–345. http://dx.doi.org/10.2307/40270875.

Fu, B.J., Su, Chang-Hong, W., Yong-Ping, W., Ian, R., Lü, Y.H., Liu, G.H., 2011. Double counting in ecosystem services valuation: causes and countermeasures. Ecol. Res. 261, 1–14. http://dx.doi.org/10.1007/s11284-010-0766-3.

Furnas, M., 2003. Catchments and Corals: Terrestrial Runoff to the Great Barrier Reef. Great Barrier Reef Marine Park Authority, Townsville, Qld.

Getzner, M., Spash, C., Stagl, S., 2005. Alternatives for Environmental Valuation. Routledge, New York.

Goldman, S.M., Uzawa, H., 1964. A note on separability in demand analysis. Econ.: J. Econ. Soc., 387–398.

Government Statistician, 2013. Queensland Regional Profiles: Resident Profile for the SLA4s and one SLA3 that lie within the GBRCA Region. Queensland Treasury and Trade.

Great Barrier Reef Marine Park Authority, 2009. Great Barrier Reef Outlook Report 2009. Great Barrier Reef Marine Park Authority, Townsville.

Great Barrier Reef Marine Park Authority, 2003. An economic and social valuation of implementing the representative areas program by rezoning the Great Barrier Reef Marine Park. Townsville, Australia.

Haines-Young, R. and Potschin, M., 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December 2012. EEA Framework Contract No EEA/IEA/09/003 (Download at www.cices.euor www.nottingham.ac.uk/cem).

Hanemann, M., Morey, E., 1992. Separability, partial demand systems, and consumer's surplus measures. J. Environ. Econ. Manag. 223, 241–258.

Hein, L., Van Koppen, K., De Groot, R.S., Van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecol. Econ. 572, 209–228.

Hoehn, J.P., Randall, A., 1989. Too many proposals pass the benefit cost test. Am. Econ. Rev. 793, 544–551.

Huang, J.C., Poor, P.J., Zhao, M.Q., 2007. Economic valuation of beach erosion control. Mar. Resourc. Econ. 223, 221.

Hundloe, T., Vanclay, F., Carter, M., 1987. Economic and Socio Economic Impacts of Crown of Thorns Starfish on the Great Barrier Reef. Institute of Applied Environmental Research, Griffith University.

Innes, J., Gorman, K., 2002. A Social and Economic Profile of Great Barrier Reef Coastal Communities. Report prepared for the GBRMPA. Townsville, Australia.

Kahneman, D., 2011. Thinking Fast and Slow. Farrar, Straus and Giroux, New York.

Knapman, B., Stoeckl, N., 1995. Recreation user fees: an Australian empirical investigation. Tour. Econ. 11, 5–15.

Koch, E.W., Barbier, E.B., Silliman, B.R., Reed, D.J., Perillo, G.M., Hacker, S.D., Wolanski, E., 2009. Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. Front. Ecol. Environ. 71, 29–37.

KPMG, 2000. Economic and Financial Values of the Great Barrier Reef Marine Park. Great Barrier Reef Management Park Authority, Townsville, Qld.

Kragt, M.E., Roebeling, P.C., Ruijs, A., 2009. Effects of Great Barrier Reef degradation on recreational reef-trip demand: a contingent behaviour approach. Austr. J. Agri. and Resour. Econ. 532, 213–229.

Kristoffersen, I., 2010. The metrics of subjective wellbeing: cardinality, neutrality and additivity. Econ. Record 86272, 98–123.

Kroon, F.J., Kuhnert, P.M., Henderson, B.L., Wilkinson, S.N., Kinsey-Henderson, A., A., B., Turner, R.D.R., 2012. River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. Mar. Pollut. Bull. 652012, 15.

La Notte, A., Maes, J., Grizzetti, B., Bouraoui, F., Zulian, G., 2012. Spatially explicit monetary valuation of water purification services in the Mediterranean biogeographical region. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 81 (2), 26–34.

LaFrance, J.T., 1993. Weak separability in applied welfare analysis. Am. J. Agric. Econ. 753, 770–775. http://dx.doi.org/10.2307/1243589.

Larson, S., 2009. Communicating stakeholder priorities in the Great Barrier Reef region. Soc. Nat. Resour. 22 (7), 650–664.

Larson, S., Stoeckl, N., Neil, B., Welters, R., 2013. Using resident perceptions of values associated with the Australian Tropical Rivers to identify policy and management priorities. Ecol. Econ. 94, 9–18.

Larson, S., Stoeckl, N., Farr, M., Esparon, E., The role the Great Barrier Reef plays in resident wellbeing and implications for its management. AMBIO. 2014, http://dx.doi.org/10.1007/s13280-014-0554-3.

Lasorsa, D.L., 2003. Question-order effects in surveys: the case of political interest, news attention, and knowledge. Journal. Mass Commun. Q. 803, 499–512.

Lewis, S.E., Brodie, J.E., Bainbridge, Z.T., Rohde, K.W., Davis, A.M., Masters, B.L., Schaffelke, B., 2009. Herbicides: a new threat to the Great Barrier Reef. Environ. Pollut. 157, 2470–2484.

Loomis, J., Kent, P., Strange, L., Fausch, K., Covich, A., 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecol. Econ. 331, 103–117.

MacKerron, G., Mourato, S., 2013. Happiness is greater in natural environments. Global Environ. Change 23, 992–1000.

Mathieu, L.F., Langford, I.H., Kenyon, W., 2003. Valuing marine parks in a developing country: a case study of the Seychelles. Environment and Development Economics 8, 373–390.

McArthur, L.C., Boland, J.W., 2006. The economic contribution of seagrass to secondary production in South Australia. Ecol. Modell. 1961, 163–172.

McKirdy, E., 2014. Australia to dump dredged sand in Great Barrier Reef Park. Retrieved from CNN website: 〈http://edition.cnn.com/2014/01/31/world/asia/great-barrier-reef-dump-approved/〉 also 〈http://www.smh.com.au/environment/conservation/mining-dwarfs-farming-as-threat-to-health-of-great-barrier-reef-marine-scientist-warns-20131211-2z6im.html〉.

Millenium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington, DC.

Mitchell, R.C., Carson, R.T., 1989. Using surveys to Value Public Goods: The Contingent Valuation Method. Resource for the Future, Washington, DC.

Moschini, G.C., 2001. A flexible multistage demand system based on indirect separability. South. Econ. J. 681, 22–41. http://dx.doi.org/10.2307/1061509.

Murphy, I., 2002a. Mackay and Whitsunday Region: Spending Habits of Recreational Fishermen and their Contribution to the Economy. Sunfish and Queensland Industry of Recreational Fishing, Margate, Qld.

Murphy, I., 2002b. Townsville and Thuringowa: Spending Habits of Recreational Fishermen and Their Contribution to the Economy. Sunfish and Queensland Industry of Recreational Fishing, Margate, Qld.

Oxford Economics, 2009. Valuing the effects of Great Barrier Reef Bleaching. The Great Barrier Reef Foundation, Australia.

Pascal, U., Muradian, R., Brander, L., Gomez-Baggethun, E., Martin-Lopez, B., Berma, M., & Christie, M. TEEB Chapter 5: The Economics of Valuing Ecosystem Services and Biodiversity. The Economics of Ecosystems and Biodiversity. Available at: 〈http://www.teebweb.org/wp-content/uploads/2013/04/D0-Chapter-5-The-economics-of-valuing-ecosystem-services-and-biodiversity.pdf〉.

Prayaga, P., Rolfe, J., Stoeckl, N., 2010. The value of recreational fishing in the Great Barrier Reef, Australia: a pooled revealed preference and contingent behaviour model. Mar. Policy 342, 244–251.

Productivity Commission, 2003. Industries, Land Use and Water Quality in the GreatBarrier Reef Catchment. 〈http://www.pc.gov.au/study/gbr/finalreport/gbr.pdf〉 [Online].

Rolfe, J., Gregg, D., Tucker, G., 2011. Valuing Local Recreation in the Great Barrier, Environmental Economics Research Hub Research Report No. 102. Available at: 〈http://www.cqu.edu.au/__data/assets/pdf_file/0006/21984/EERH_RR102.pdf〉.

Rolfe, J., Windle, J., 2011. Using auction mechanisms to reveal costs for water quality improvements in Great Barrier Reef catchments in Australia. Agric. Water Manag. 984, 493–501.

Rolfe, J., Windle, J., 2012a. Distance decay functions for iconic assets: assessing national values to protect the health of the Great Barrier Reef in Australia. Environ. Resour. Econ. 533, 347–365.

Rolfe, J., Windle, J., 2012b. Testing benefit transfer of reef protection values between local case studies: the Great Barrier Reef in Australia. Ecol. Econ. 81, 60–69.

Rolfe, J., Gregg, D., 2012. Valuing beach recreation across a regional area: the Great Barrier Reef in Australia. Ocean &. Coast. Manag. 69, 282–290.

Sathirathai, S., Barbier, E.B., 2001. Valuing mangrove conservation in southern Thailand. Contemp. Econ. Policy 192, 109–122.

Silva, J., Brown, Z., 2013. More than the Sum of Their Parts: Valuing Environmental Quality by Combining Life Satisfaction Surveys and GIS Data. OECD Publishing.

Smith, V.K., Palmquist, R.B., Jakus, P., 1991. Combining Farrell frontier and hedonic travel cost models for valuing estuarine quality. Rev. Econ. Stat. 73 (4), 694–699.

Stoeckl, N., Esparon, M., Stanley, O., Farr, M., Delisle, A., Altai, Z., 2013 The great asymmetric divide: an empirical investigation of the link between Indigenous and non-Indigenous economic systems in Northern Australia, Papers Reg. Sci., http://dx.doi.org/10.1111/pirs.12028.

Stoeckl, N., Hicks, C., Mills, M., Fabricius, K., Esparon, M., Kroon, F., Kaur, K., Costanza, R., 2011. The economic value of ecosystem services in the Great Barrier Reef: State of knowledge and information gaps. In: Costanza, Robert, Limburg, Karin, Kubiszewski, Ida (Eds.), Ecological Economics Rev., 1219. Annals of the New York Academy of Sciences, pp. 113–133.

Stoeckl, N., Birtles, A., Farr, M., Mangott, A., Curnock, M., Valentine, P., 2010. Live-aboard dive boats in the Great Barrier Reef: regional economic impact and the relative values of their target marine species. Tour. Econ. 164, 995–1018.

Swait, J., Adamowicz, W., 2001. The influence of task complexity on consumer choice: a latent class model of decision strategy switching. J. Cons. Res. 281, 135–148. http://dx.doi.org/10.1086/321952.

Tourism Queensland, 2013, Tourism Economic Key Facts. Available at: 〈http://www.tq.com.au/fms/tq_corporate/research%20%28NEW%29/Destination%20Visitor%20Data/QLD%20Tourism%20Economic%20Key%20Facts%20July%202013.pdf〉.

Van Praag, B.M.S., Baarsma, B.E., 2005. Using happiness surveys to value intangibles: the case of airport noise. Econ. J. 115500, 224–246. http://dx.doi.org/10.2307/3590511.

Watson, R.A., Coles, R.G., Long, W.J.L., 1993. Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland, Australia. Mar. Freshwater Res. 441, 211–219.

Welsch, H., 2006. Environment and happiness: valuation of air pollution using life satisfaction data. Ecol. Econ. 584, 801–813. http://dx.doi.org/10.1016/j.ecolecon.2005.09.006.

White, A.T., Vogt, H.P., Arin, T., 2000. Philippine coral reefs under threat: the economic losses caused by reef destruction. Mar. Pollut. Bull. 407, 598–605.

Wilkinson, C., Lindén, O., Cesar, H., Hodgson, G., Rubens, J., Strong, A.E., 1999. Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: an ENSO impact and a warning of future change? Ambio 28, 188–196.

Windle, J., Rolfe, J., 2005. Assessing non-use values for environmental protection of an estuary in a Great Barrier Reef catchment. Australas. J. Environ. Manag. 123, 147–155.

Zander, K.K., Straton, A., 2010. An economic assessment of the value of tropical river ecosystem services: heterogeneous preferences among Aboriginal and non-Aboriginal Australians. Ecol. Econ. 69 (12), 2417–2426.