Evidence of economic benefits for public investment in MPAs

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A B S T R A C T

MPAs enhance some of the Ecosystem Services (ES) provided by coral reefs and clear, robust valuations of these impacts may help to improve stakeholder support and better inform decision-makers. Pursuant to this goal, Cost-Benefit Analyses (CBA) of MPAs in 2 different contexts were analysed: a community based MPA with low tourism pressure in Vanuatu, and a government managed MPA with relatively high tourism pressure, in Saint Martin. Assessments were made on six ES: fish biomass, scenic beauty, protection against coastal erosion, bequest and existence values, social capital and CO2 sequestration, which were quantified via different approaches that included experimental fishery, surveys and benefit transfer. Total operating costs for each MPA were collected and the benefit-cost ratio and return on investment based on 25-year discounted projections computed. Sensitivity analyses were conducted on MPA impacts, and discount rates (5%, 7% and 10%). The investment indicators all showed positive results with the impact on the tourism ES being the largest estimated for all MPAs, highlighting the importance of this relationship. The study also demonstrated a relatively high sensitivity of the results to different levels of impacts on ES, which highlights the need for reducing scientific knowledge gaps.

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1. Introduction

Marine protected areas (MPAs) are clearly defined geographical spaces which are recognised and managed through legal or other effective means, to achieve long-term conservation of nature with associated ecosystem services and cultural values (IUCN-WCPA, 2008). MPAs are considered to be effective tools in managing coral reef ecosystems for ecological objectives (Salm et al., 2000, Halpern, 2003). The ecological benefits of MPAs on fish and invertebrate resources inside the boundaries of reserves, as well as in the surrounding areas, are now well established (Sale et al., 2005). Several international policy fora have called for the global expansion of MPAs. The predominant statements are from the Durban Action Plan and the Convention on Biological Diversity (CBD) Aichi Target 11. More recently, the ‘Promise of Sydney’ statement issued by the 2014 World Parks Congress recommends that we “urgently increase the ocean area that is effectively and equitably managed in ecologically representative and well-connected sys-

tems of MPAs or other effective conservation measures”, with an ultimate aim of creating a fully sustainable ocean, with at least 30% set aside for no extraction. While some progress has been made towards meeting these targets, considerably more needs to be done in order to ensure the expanded geographic coverage as well as effectiveness and ecological representativeness of MPAs (Ban et al., 2014, Dunn et al., 2014, Fox et al., 2014).

The economic benefits of investing in MPAs are derived from improvements in the quality of the natural environment, which strengthens the capacity of coastal and marine ecosystems to produce ecosystem services for local populations, businesses and the global community (TEEB, 2010a). On the cost side, the start-up and management costs of MPAs are among the major hurdles in gaining support for the initiation of MPAs worldwide (Balmford et al., 2004, Mora et al., 2006). The Cost Benefit Analysis (CBA) approach is a way to inform and convince stakeholders of the potential returns from investing in marine protection (Gowdy, 2007).

Determining the CBA of marine conservation projects such as MPAs however, is far from being a consolidated approach. On one hand, the approach faces similar issues as ES valuation exercises (Laurans et al., 2013) in terms of the methodological
limitations of obtaining the required information on welfare derived from ES. In addition, CBA has to take into account major uncertainties regarding MPA impacts on fishery yields, tourism revenues, coastal protection and other ES (Boersma and Parrish, 1999, Wilkie et al., 2006).

We analyze the methods and results of two existing CBAs of MPAs. The first is a network of community-based MPAs in the Vanuatu Islands (South Pacific) while the second is a government managed MPA in Saint Martin (French West Indies). These cases represent two different geographic and institutional contexts. Sensitivity analyses are carried out on the parameters of each CBA to improve our understanding of the robustness of the results. We examine the usefulness of CBAs of MPAs for decision-making and discuss how this tool can be further developed.

2. Material and methods

2.1. Description of the study sites

The analysis examines two MPAs, one in Vanuatu and the other in Saint Martin. The MPA situated in Efate, Vanuatu (South-West Pacific) is comprised of a group of five small MPAs, which are independent from each other, but linked via a network. The MPA in Saint Martin (French West Indies) comprises one large MPA (Fig. 1). The main socio-ecological characteristics of the sites are described in Table 1. Each of the MPA sites fulfills the following criteria: (i) proximity of economic activities (mainly fishing, tourism and human settlements) (ii) active management and adequate enforcement of the MPA (by communities or government) for at least five years and, (iii) the reserve covers at least 10% of the fishing grounds.

2.2. Description of the selected MPA impacts

Six ES categories were chosen for analysis: (i) subsistence and commercial reef fishing (ES1, also named as ‘fishery’) (ii) scenic beauty and emblematic species for tourism (scuba diving, recreational boating, charters, etc.) and associated activities (accommodation, food, etc.) (ES2, also named as ‘tourism’), (iii) protection against coastal floods (ES3, also named as ‘coastal protection’), (iv) non-use values of the ecosystems (ES4, also named as ‘bequest value’), (v) social capital impacts, defined as the ability to encourage collective action through external assistance (ES5 can be considered as one of the many multidimensional aspects of the concept of ‘social capital’) and (vi) CO2 sequestration by mangroves (ES6, also named as ‘carbon sequestration’).

When several methods were available, preference was given to those producing the most conservative values (Beukering et al., 2007).

2.3. Quantification and valuation of ES

Quantification and valuation of these six categories of ES requires a variety of measurement methods (Table 2). The valuation methods were developed following recent guidance produced by The Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2010b) and other manuals (Beukering et al., 2007, Balmford et al., 2008, Defra, 2008). Although the methodology sought to be homogenous across sites, some modifications were needed to better suit the unique ecological and socioeconomic conditions of each scenario.

For ES1 in Vanuatu, the producer surplus (the difference between the amount the producer is willing to supply goods for and the actual amount received by him) for commercial fisheries was calculated from data collected from fishing logbooks over the course of 2 years (n = 96 h of spearfishing), interviews with fishermen (n = 25), experimental Catch Per Unit Effort (CPUE) (45 h of net-fishing) and household and income expense surveys in two villages (n = 12 households). Estimates of CPUE (e.g. kg of fish captured per hour of standard fishing effort for net and spearfishing), annual fishing effort (h.net / C0 or h.spearfishing / C0), protein content and fishery revenues were then produced. The value for subsistence fishing was produced by converting the amount of fish caught to the monetary value of an equivalent amount of animal protein from a different source (e.g. chicken or pork). In Saint Martin, data were collected from fishers and cooperatives’ surveys (n = 11) conducted in 2012. The surveys allowed for the quantification of fishing frequency per gear type, target species and catch per trip, as well as investment and operational costs of the activity. For both sites, the fisheries are small scale with fishers...
carrying out their activity in areas close to the MPAs. There is also a very limited fishing effort from “outsiders” in the studied fishing grounds.

For ES2, in both countries, the producer surplus corresponded to the value of the selected tourism activities directly related to the processes produced by coral reef ecosystems. The data collection method, however differed in each country. In Vanuatu, expenditure details and occupancy rates data were collected through interviews (n = 45), which were conducted on a monthly basis during 6 months (June to November). The majority of the tourism professionals were located in the interviewed study zone. Interviews with other professionals included all the diving clubs and most of the tour operators. Data were completed with official tourism statistics (Vanuatu National Statistics Office, 2008). In Saint Martin, expenditure estimates were based on business declarations of the number of their clients sent every month to the MPA by diving clubs and day tour operators (n = 38). These declarations were used to calculate the monthly fees collected from users. The associated average expenses on accommodation, food, local transport and souvenirs were estimated through existing tourism statistics (INSEE, 2008). Intermediary costs for the primary tourism businesses (service provider and accommodation sectors) were collected via professional interviews and compared with costs from other studies. Data on recreational boating expenditures and added value were estimated based on available information of boat use frequencies in the MPA (Rastoin, 2011) and completed by interview (n = 8) with the main boating associations (sport fishing, harbours, yacht clubs) and professionals (sailing charters, brokers, maintenance operators).

For ES3 (coastal protection), the damage costs avoided by the presence of the protected ecosystems were assessed in a similar manner in both countries. The coastal areas potentially at risk from wave damage were identified, then the contribution of reefs and mangroves to the protection of vulnerable areas was estimated and finally the potential impacts on residential buildings and infrastructure were quantified and monetized, using the expected likelihood of a damaging event. Quantification of ES values utilised a bio-physical model developed for the valuation of ES in low-data availability situations (Burke et al., 2008, Pascal et al., 2016). The model allows us to define the coastal protection index (low-medium-high) of each segment of coastline with seven physical characteristics: coastal geomorphology, exposure of the coast, wave energy (usually the maximum wave height), frequency of storms, characteristics of coral reefs, coastal vegetation (man-

Table 1

<table>
<thead>
<tr>
<th>Ecosystem service</th>
<th>Valuation method</th>
<th>MPA contributing factor</th>
<th>Spatial perimeter</th>
<th>Estimated contributing factor as % of ES value. Sensitivity analysis values in (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsistence and commercial fishing</td>
<td>ES 1 Producer surplus</td>
<td>MPA impact on fishing productivity</td>
<td>Spillover and larval dispersion zone</td>
<td>25% (6–25–33%)</td>
</tr>
<tr>
<td>Tourism and associated expenses</td>
<td>ES 2 Producer surplus</td>
<td>Contribution in tourism expenses</td>
<td>MPA coastline</td>
<td>70% (50–70–90%)</td>
</tr>
<tr>
<td>Coastal protection</td>
<td>ES 3 Avoided damage costs</td>
<td>Impact on wave energy absorption mechanisms</td>
<td>MPA coastline</td>
<td>5% (3–5–10%)</td>
</tr>
<tr>
<td>Bequest value</td>
<td>ES 4 Transfer benefit</td>
<td>Impact on ecosystem existence</td>
<td>MPA</td>
<td>35% (20–35–50%)</td>
</tr>
<tr>
<td>Social capital</td>
<td>ES 5 Direct expenditures</td>
<td>Proportion of grants linked to the MPA</td>
<td>MPA</td>
<td>Not Available</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td>ES 6 Market value of carbon credits</td>
<td>MPA impact on avoided habitat conversion</td>
<td>MPA</td>
<td>10% (5–10–15%)</td>
</tr>
</tbody>
</table>

Table 2

General description of the six MPAs and control sites involved in the study.

<table>
<thead>
<tr>
<th>MPA sites</th>
<th>Control sites</th>
<th>Sources of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emua</td>
<td>Nekapa</td>
<td>INSEE (2009);</td>
</tr>
<tr>
<td>Piliura</td>
<td></td>
<td>INSEE (2009);</td>
</tr>
<tr>
<td>Unakap</td>
<td>Saama</td>
<td>INSEE (2010);</td>
</tr>
<tr>
<td>Laonamoa</td>
<td></td>
<td>INSEE (2010);</td>
</tr>
<tr>
<td>Worasifu</td>
<td></td>
<td>INSEE (2010);</td>
</tr>
<tr>
<td>Vanaatu</td>
<td></td>
<td>Description in</td>
</tr>
<tr>
<td>St Martin</td>
<td></td>
<td>the text</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resident population</th>
<th>Demographic pressure on reef (hab/km2 of reef)</th>
<th>Human density (hab.km−2)</th>
<th>Monthly average household incomes (monetary and non monetary) (PPP US$, 2010)</th>
<th>Monthly average non monetary incomes (% total incomes)</th>
<th>Fishing ground (km2)</th>
<th>Tourism infrastructure (number of beds) in MPA perimeter</th>
<th>Fishing pressure index</th>
<th>MPA creation date</th>
<th>MPA size (km2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>157</td>
<td>300</td>
<td>335</td>
<td>31%</td>
<td>1,5</td>
<td>5</td>
<td>3,1</td>
<td>2005</td>
<td>0,24</td>
</tr>
<tr>
<td>110</td>
<td>102</td>
<td>275</td>
<td>261</td>
<td>40%</td>
<td>1,1</td>
<td>8</td>
<td>3</td>
<td>2003</td>
<td>0,13</td>
</tr>
<tr>
<td>90</td>
<td>71</td>
<td>450</td>
<td>272</td>
<td>40%</td>
<td>1,3</td>
<td>14</td>
<td>3,75</td>
<td>2003</td>
<td>0,12</td>
</tr>
<tr>
<td>250</td>
<td>188</td>
<td>417</td>
<td>294</td>
<td>36%</td>
<td>1,3</td>
<td>5</td>
<td>3,65</td>
<td>2003</td>
<td>0,14</td>
</tr>
<tr>
<td>50</td>
<td>104</td>
<td>167</td>
<td>294</td>
<td>36%</td>
<td>0,5</td>
<td>6</td>
<td>2,97</td>
<td>2000–2001</td>
<td>0,13</td>
</tr>
<tr>
<td>740</td>
<td>124</td>
<td>840</td>
<td>291</td>
<td>N.A.</td>
<td>128</td>
<td>50</td>
<td>4,7</td>
<td>–</td>
<td>0,75</td>
</tr>
<tr>
<td>45.000</td>
<td>21,226</td>
<td>275</td>
<td>671</td>
<td>36%</td>
<td>128</td>
<td>50</td>
<td>16.500</td>
<td>–</td>
<td>27,96</td>
</tr>
<tr>
<td>110</td>
<td>92</td>
<td>275</td>
<td>306</td>
<td>36%</td>
<td>128</td>
<td>50</td>
<td>3,05</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>130</td>
<td>144</td>
<td>217</td>
<td>318</td>
<td>31%</td>
<td>128</td>
<td>50</td>
<td>3,25</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Description in the text</td>
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</tr>
</tbody>
</table>

NB: The synthetic fishing pressure index was developed to compare the fishery effort potential between MPA sites and the control sites. The index is a score based on several characteristics of fishing effort standardized per km² of fishing ground for each site (number of gears, storage devices, “regular” fishermen and transport infrastructure).
groves, wetlands, etc.) elevation and slope of the coast. Avoided damage valuation was assessed on potential residential and infrastructure damages. In vulnerable zones, the potential impacts were valued using geographic analysis. Urban and rural areas were differentiated and mean real estate prices collected from available data sources (home owners, real estate agencies, the internet).

For ES4, the benefit transfer method was used in Vanuatu based on existing studies that estimated bequest and option values of coral reefs for villages in Fiji (O’Garra, 2012). The socio-ecological context of this study displayed similarities with Vanuatu, including customary management of marine tenure, small villages, small fringing reefs, and an emergent market economy in which subsistence, barter and market exchanges are mixed. The economic values were obtained from villagers through willingness to contribute (in hours/week) towards conservation of their marine zone, in order to maintain some of the ES (presented as option and bequest values by the author, even though it might be argued that the value also includes direct uses). In the case of Saint Martin, a review of selected non-use valuation studies in the Caribbean (Park et al., 2000, Rudd et al., 2001, Raboteur and Rodes, 2006, Parsons and Thur, 2007, Wielgus et al., 2009) failed to provide the conditions required for results to be used in a benefit transfer protocol (Rosenberger and Loomis, 2001, Wilson and Hoehn, 2006), and so these estimates were excluded.

In this context, social capital (ES5) refers to the capacity of the community to be represented in external events (Putnam, 2006, Barnes-Mauthe et al., 2015) and we chose to focus on one aspect of this capital, which is the ability to attract external assistance through grants or technical support. In both countries, data were collected from the census of all grants and assistance related to marine ecosystem management. Based on historical observations of past external assistance, a periodic flow (every 7 years) of support, after the creation of the MPA was applied.

ES6 (carbon sequestration) is primarily provided by mangroves and seagrass ecosystems (Sifleet et al., 2011). Results obtained were based on the methodology developed by several authors (Duarte and Middleburg, 2005, Bouillon et al., 2009, Murray et al., 2010, Nicholas Institute for Environmental Policy Solutions, 2011). Following the additivity approach (Peters-Stanley et al., 2013), calculations were based on the volume of CO2 eq. annually avoided from being released into the atmosphere, by maintaining ecosystems in their current state. Following our general preference for conservative values and safe-minimum estimates, we chose the value of market carbon credits rather than using the social cost of carbon (US EPA (U.S. Environmental Protection Agency) 2013). The prices of carbon credits were estimated from market data (Forest Trends Ecosystem Marketplace and Bloomberg New Energy Finance, 2014). Due to the limited presence of mangrove and seagrass habitats in the Vanuatu sites, this aspect of the valuation was only conducted in Saint Martin.

2.4. Valuation methods of impacts of MPAs on ES

The valuations of both MPAs focused on the identification of the factor of the MPA to the value of the ES, in order to isolate the MPA’s effects. The control-impact approach has been proposed by several authors as a way to address this issue (Smith, 2002, Halpern, 2003). In control (non-MPA) and impact sites (MPA), the following studies were conducted: (i) a comparative assessment of the ecological factors using the Medium Scale Approach (Clua et al., 2006), specifically designed for commercial reef fisheries, (ii) a comparative assessment of fishing effort and (iii) a comparative assessment of tourism attractiveness resulting from objective indicators of site accessibility (e.g. distance to airport, infrastructure, price) for visitors. In Vanuatu, two villages served as control sites (Table 1). In Saint Martin however, it was not possible to locate any valid control sites due to the relatively small area located outside of the MPA boundaries (the MPA covers approximately half of the island). Hereafter, we describe the details of the calculations for the MPA impact on ES.

An additional challenge of MPA valuation is whether the potential benefits of the MPA impacts will be experienced by the local community, the national private sector, or by international entities. This knowledge can help make the case for public or private investment. To achieve this a certain understanding of the spatial boundary of the MPA impacts is needed. This task can be difficult considering knowledge gaps of larval dispersion, species migration, and other factors related to the interconnectedness of marine ecosystems. In addition, the areas where beneficiaries are found may not coincide with the location of the impacts. A good example is the leakage effect for tourism benefits (Garrigós-Simón et al., 2015) showing the volume of tourism revenues that does not remain in the destination economy. To address this issue there needs to be not only an ecological understanding of the site but a socioeconomic understanding as well. This task has been confronted through the use of simplified assumptions and proxies described thereafter.

The MPAs’ impacts on ES1 were calculated through the identification of the effect of MPAs on CPUEs for main gear type. The results were obtained from an experimental fishery and logbook data collection effort conducted in Vanuatu and described previously. Vanuatu’s MPA sites demonstrate higher fish productivity than non-MPA locations. The estimated increase in catch productivity is between 15% and 33% (kg.h^{-1}) higher for gillnet and 6–22% (kg.h^{-1}) for speargun harvest techniques (Pascal, 2013). We assumed that this productivity enhancement represents a proxy of the MPA contributive factor on fishery added value (ES1). A direct gradient analysis (redundancy analysis: RDA and partial RDA) on data (Legendre and Anderson, 1999) was conducted to differentiate between the explanatory variables linked to the MPA (e.g. existence, distance from border) and those linked to the context (e.g. moon cycle, tide and habitat variables including depth, coral reef description and substrate category). The absence of “outsider” fisheries and the prevalence of subsistence fishing yield the assumption that the benefits are experienced by the local communities.

The effect of MPAs on tourism is reflected in the role of the reserve in visitor destination choice. Estimates were based on specific questions in individual surveys, conducted with end-users (Vanuatu n = 34 (Pascal, 2013), Saint Martin, n = 110 (Malterre P et al., 2011). The respondents were asked to answer specific questions about the importance of the MPA and ecological attributes expected to be enhanced by the MPA (i.e. beauty of the sea scapes and the diversity and abundance of fish) in their destination choice. These questions provide information about a variable ”MPA_factor”. It takes a value between 0 and 1 following the proportion of time devoted to activities/MPA visit for the duration of the stay, the main motivation for travel and the importance of these activities in the choice of destination. factors, expressed as a percentage of the added value of tourism expenses (ES2), varied between 10% (Saint Martin) and 70% (for some sites in Vanuatu). They were both completed with studies of tourism Advertising Image Analysis (AIA) (Hajkowicz et al., 2005) based on a minimum of 100 images and identifying the weight of images or references made specifically to the MPA or the marine biodiversity in regard to other categories of tourism attributes (cultural and people, ecosystems and landscapes, beaches, other forms of entertainment). They highlighted that marine ecosystem attributes and MPA images represent approximately 20% of all the images in both sites. In Vanuatu sites, there is little international investment so the benefits are primarily received locally and by the national private sector. In St. Martin, part of the tourism sector is owned by
international investors (Tourism and Transport Consult, 2005) but, to our knowledge, no leakage calculations have been assessed.

The determination of the contribution of the MPA to the production of ES3 must take into account that the ES is more dependent on physical than biological factors (Pascal et al., 2016). As MPAs strengthened mainly the biological factors, with little evidence of influence on the physical factors driving the production of the ES (Halpern, 2003) and without any supporting literature, a low factor (5%) of the value of the ES, was proposed. Private and public infrastructure at both sites experience protection from coastal processes due to ES3.

Regarding bequest value (ES4) that people may ascribe to the coral reef, none of the available studies assessed were sufficiently precise to determine the role played by the MPA in the valuation. Therefore, based on existing evidence of MPA impacts on habitats and biodiversity (Sale et al., 2005), we applied a contributing factor of 35% on the ES valuation.

The effect of the MPA on the ES5 is calculated as the proportion of the grants or assistance received due to its existence. The role was assessed through interviews with grant recipients (village committees, NGOs or MPA managers).

The impacts of the MPA on ES6 were based on the existing literature and expert opinions, in order to assess the level of conversion or degradation threats on the mangrove habitats in Saint Martin. Based on an annual loss surface of habitat avoided by the existence of the MPA regulations (3–25 ha.y⁻¹ of mangrove habitat non destroyed), the factor of the MPA was estimated at 10%.

The benefits for ES4, ES5, and ES6 can be far-reaching (Balmford et al., 2008). They can be experienced by the local, national and international communities in terms of the existence value, conservation of biodiversity, and the removal of carbon from the atmosphere.

2.5. Costs of MPAs

Different kinds of MPA costs were distinguished: direct operational costs, initial investment and opportunity costs. The direct operational costs include administration, employment, monitoring and enforcement. The investment costs refer to the establishment costs, transaction costs, and material assets such as boats, buoys, signboards, etc. The opportunity costs consider all the potential earnings such as losses in the fishery revenues, longer displacement time for fishermen or loss from the time spent in the MPA management. The jobs created by the MPAs (in management, monitoring and enforcement) were considered here as a cost, considering that in the absence of the MPA, workers would have obtained another similar level of job elsewhere. Other opportunity costs linked to the MPA establishment for tourism (e.g. new advertising material, relocation of tours, etc.) are very limited in both islands and have not been incorporated in the study. For investment costs, normal rules of accountancy were applied to calculate annual amortizing costs (i.e. based on life expectancy of the assets).

2.6. Economic and financial analysis

The ex-post Return on Investment (RoI) was calculated following standard methods (Campbell and Brown, 2003). It is based on the observed historic cash flows of impacts on ES1 and ES2 and compared to the direct and investment costs (without amortizing). RoI was calculated on discounted values for the period from the creation of each MPA, to the study date (10 years for Saint Martin and 6–8 years for Vanuatu).

In addition to the ex-post study, an ex-ante CBA was undertaken based on the present values of projections of the impacts (Wielgus et al., 2008). Projections are made under simplifying assumptions incorporated into a scenario that takes into account the potential for development of tourism and fisheries in each country. Following existing studies (Wielgus et al., 2008), the projections cover a period of 25 years after the creation of the MPA. This range was proposed in similar studies to reflect the ecological responses of ecosystems to the tested scenario (Balmford et al., 2008). The period starts from the first payment of investment costs and/or the beginning of enforcement activities (2001 for Saint Martin and 2002/2004 for Vanuatu). A Benefit Cost Ratio (BCR) is calculated on the flows of average values of impacts on all ES and costs. We apply a discount rate of 10% in computing present values (Ehrlich, 2008) even though lower discount rates have been argued to be more appropriate when assessing investment in nature (TEEB, 2010b) in order have the most disadvantageous situation possible (Weitzman, 2001). Using this rate strengthens any positive conclusions (BCR > 1) that are reached.

2.7. Sensitivity analysis

Sensitivity analyses were carried out to better understand the robustness of our estimates (Cesar and Chong, 2006). Analyses focused on the different estimates of the MPA factors for each of the 6 ES (Table 3). The chosen method is through an “extreme case” approach that allows, through non-intensive techniques, the identification of those inputs that generate the most sensitivity (Boardman et al., 1996). The levels presented are based on minimum and maximum estimates of the factor, whereas the best estimate represents the average value. Sensitivity analyses were conducted for the BCR and RoI results.

An additional sensitivity analysis was carried out on the benefit estimate of the BCR for different discount rates (5%, 7%, 10%) (Pearce et al., 2006).

3. RESULTS

3.1. Impacts on ES

The mean economic impacts have been estimated at US$ 44,200 (+/− 19,800) per year per km² for the five MPAs in Vanuatu and US$ 29,800 per year per km² for the MPA in Saint Martin (Table 3). For both case studies, the impacts of the MPA on tourism, represent the greatest proportion of the total effect (60–70%). Tourism effects were followed by effects on the fishery added value (25%) in Vanuatu and coastal protection (23%) in Saint Martin.

On a per surface area basis, the MPA impacts on the tourism sector were similar across sites (Table 3). ES2 associated with the MPA generates a value of US$ 21,446 in 2010 in Saint Martin, shared among the private nautical sector (15%), scuba diving (15%), day charters (10%), boat rental (10%) and glass-bottom boats (10%). In 2009 in Vanuatu, the average ES2 was assessed at US$ 33,000 with a MPA impact ($US 25,375) shared between day tours (60%) and guest-houses (40%). The differences in the contributions of MPA impacts in the ES2 values (8% and 70% for Saint Martin and Vanuatu respectively) highlight the different motivations and expenditure behaviours between the specific nature tourism niche in Vanuatu and a mass tourism destination in Saint Martin. Complementary results about other MPA impacts per ES are given in Table 3.

3.2. Financial and economic results

The total direct costs without amortizing (Table 4) are US$ 1,800 per year and US$ 300,000 per year for Vanuatu and Saint Martin, respectively. However, on a per area basis, these direct costs are quite similar (US$ 12,100 vs 10,700 per year per km²).
The BCR is calculated as the expected net benefits of the MPA over a 25-year project life and evaluated at a 10% discount rate (Table 5). Using these parameters, we calculate a BCR between 2 and 4.1. The longer the MPA life, the higher the ratio, due to the initial establishment costs being spread over more years. It also reflects the potential of future development of the tourism and fisheries sectors in Vanuatu.

The positive BCR for all the studied MPAs demonstrates that investment in marine reserves, in addition to conservation of coral reefs, is an effective means of investing in economic development.

The results of the RoI are based on the present values of observed impacts from the date of the MPA creation up to 2009–2010 (Table 6). The mean RoI of Vanuatu MPAs is 0.8 (+/-0.6) after 6–8 years of activity. For Saint Martin, the RoI is 0.6 after 10 years of activity. The positive results of RoI mean that the benefits exceed the costs after several years of activity and that public investment in MPAs can produce benefits which are greater than the costs, even if based only on the historic fishery and tourism business benefits (ES1 and ES2).

### Table 3
Synthesis of the main results in terms of ES valuation and MPA impacts.

<table>
<thead>
<tr>
<th></th>
<th>2009 and 2010 data, US$ y  -1 km -2 of MPA</th>
<th></th>
<th>MPA impacts (US$ km  -2 of MPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vanuatu (mean)</td>
<td>St Martin</td>
<td>Vanuatu (mean)</td>
</tr>
<tr>
<td>Subsistence and commercial fishery (ES1)</td>
<td>42.846</td>
<td>837</td>
<td>10.863</td>
</tr>
<tr>
<td>Tourism (ES2)</td>
<td>32.614</td>
<td>329.290</td>
<td>25.375</td>
</tr>
<tr>
<td>Coastal protection (ES3)</td>
<td>34.319</td>
<td>83.596</td>
<td>3.339</td>
</tr>
<tr>
<td>Bequest value (ES4)</td>
<td>8.745</td>
<td>N.A.</td>
<td>2.993</td>
</tr>
<tr>
<td>Social capital (ES5)</td>
<td>1.675</td>
<td>589</td>
<td>1.648</td>
</tr>
<tr>
<td>CO2 sequestration (ES6)</td>
<td>N.A.</td>
<td>6.842</td>
<td>N.A.</td>
</tr>
<tr>
<td>TOTAL MPA impacts</td>
<td>120.199</td>
<td>421.144</td>
<td>44.218</td>
</tr>
</tbody>
</table>

### Table 4
Synthesis of the main results in terms of MPA costs.

<table>
<thead>
<tr>
<th>MPA costs (US$ y  -1 km -2 of MPA)</th>
<th>Vanuatu (mean)</th>
<th>St Martin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct costs without amortizing</td>
<td>-12.110</td>
<td>-10.740</td>
</tr>
<tr>
<td>Initial investment and material assets</td>
<td>-56.231</td>
<td>-18.912</td>
</tr>
<tr>
<td>Amortizing costs</td>
<td>-8.033</td>
<td>-2.128</td>
</tr>
<tr>
<td>Opportunity costs</td>
<td>0</td>
<td>-2.514</td>
</tr>
<tr>
<td>TOTAL MPA annual costs with amortizing costs</td>
<td>-20.143</td>
<td>-15.382</td>
</tr>
</tbody>
</table>

### Table 5
Synthesis of the main results for BCR and present values of projected MPA impacts under scenario 2 (25 years).

<table>
<thead>
<tr>
<th></th>
<th>MPA impacts (US$ km  -2 of MPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vanuatu (mean)</td>
</tr>
<tr>
<td>Subsistence and commercial fishery (ES1)</td>
<td>73.378</td>
</tr>
<tr>
<td>Tourism (ES2)</td>
<td>188.587</td>
</tr>
<tr>
<td>Coastal protection (ES3)</td>
<td>15.136</td>
</tr>
<tr>
<td>Bequest value (ES4)</td>
<td>21.968</td>
</tr>
<tr>
<td>Social capital (ES5)</td>
<td>15.666</td>
</tr>
<tr>
<td>CO2 sequestration (ES6)</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL MPA impacts (1)</td>
<td>314.734</td>
</tr>
<tr>
<td>TOTAL MPA economic costs (2)</td>
<td>-76.165</td>
</tr>
<tr>
<td>BCR (1)/(2)</td>
<td>4.1</td>
</tr>
</tbody>
</table>

### Table 6
Synthesis of the main results for RoI ratios and present values of observed MPA impacts since the MPA creation up to 2009–2010.

<table>
<thead>
<tr>
<th>MPA impacts (US$ km  -2 of MPA)</th>
<th>Vanuatu (mean)</th>
<th>St Martin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsistence and commercial fishery (ES1)</td>
<td>15.115</td>
<td>729</td>
</tr>
<tr>
<td>Tourism (ES2)</td>
<td>34.613</td>
<td>66.471</td>
</tr>
<tr>
<td>TOTAL MPA financial impacts (1)</td>
<td>49.128</td>
<td>67.200</td>
</tr>
<tr>
<td>TOTAL MPA financial costs (2)</td>
<td>-27.932</td>
<td>-41.945</td>
</tr>
<tr>
<td>RoI ((1)/(2))</td>
<td>0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

### 3.3. Sensitivity analysis

The results of the analysis show a relative sensitivity of the BCR and RoI results to different levels of MPA factors (Fig. 2) with a 2-fold difference between minimum and maximum levels. In particular, in cases where all factors are set to their minimum value, the Vanuatu RoI becomes negative and the Saint Martin RoI ratio is close to zero after 6 years of activity, meaning that costs have exceeded or equalized the benefits. This result reflects (i) that more time is necessary to compensate for the costs of MPA and/or (ii) the investment was too high with respect to the economic benefits.

The results of the analysis on discount rates show a low sensitivity (i.e. less than 20% difference between minimum and maximum) to the different levels on the 25-year projections (Fig. 3).

### 4. Discussion

#### 4.1. Methodological approaches and reliability

This study provides some important information for decision-making on marine conservation and the need for extensive empirical studies on MPA impacts. Credible evaluations of common conservation instruments are rare (Miteva et al., 2012) and calls for rigorous evaluation of protected areas (PAs) have been made repeatedly (Vincent, 2010). It has been observed that assessments of tropical marine parks are often inaccurate as they value the resource protected and not the protection provided (Pendleton, 1995). In spite of such warnings, economic valuations of the added value, provided by management are still scarce, especially compared to the more static and descriptive studies that estimate Total Economic Values (Wielgus et al., 2010).

Our analysis has presented valuations carried out by utilising a mix of data sources, including experimental fishery with control-impact approach, empirical observations from surveys, transfer benefit and expert opinions. Even though the study demonstrates that investment in marine reserves, in addition to conserving coral reefs, is an effective means of encouraging local economic develop-
ment, the benefit-cost ratios have proven to be sensitive to the primary uncertainties regarding the extent to which MPAs impact ES provision. This raises the requirement for (i) filling scientific gaps regarding impacts of MPAs on ES, with multidisciplinary inputs, in order to provide robust information for decision-making and, (ii) future studies to include more systematically designed sensitivity analyses. As noted by François and Pascal (2012), in their review of 17 CBAs on MPAs on coral reef ecosystems, most CBAs neglect to provide any sensitivity analyses on the results. The analysts should employ the use of non-intensive sensitivity analysis techniques, in order to identify those inputs that generate the greatest sensitivity. Several such methods are available (EPA 2009), including extreme case (min–max) analyses, Monte Carlo and variance-based methods.

Additionally, for most of the ES, the relationship with coral reef ecosystems is non-linear (Jennings and Polunin, 1995, Halpern, 2003, Barbier et al., 2008, Ban et al., 2011), which means that a marginal increase in the area or quality of the ecosystem will not necessarily translate into a proportional increase in services. In particular, the ecosystem is likely to respond very differently at extremely small sizes (Halpern, 2003) or when it is close to disappearance (threshold effects) (Ban et al., 2011). These relationships are unlikely to be linear, although due to the difficulty in estimating these values, this has been the overwhelming assumption in the literature reviewed. Dynamic links between investment and ecosystem services are far from being well-known and almost all of the reviewed studies have focused on average values. The marginal values of ES that depend directly on the ecosystem’s productivity can only be estimated if an ecological function which provides the change in service, exists in the literature. Different authors (Cesar, 1996, Cesar and Beukering, 2002, Gunawardena and Rowan, 2005) have estimated the marginal change in the value of fisheries by looking at the increase in production from a marginal change in the ecosystem and the consequent change in pro-

![Fig. 2. Sensitivity analysis of BCR and RoI to main uncertainties on MPA factor.](image)

![Fig. 3. Sensitivity analysis of BCR based on three discount rates (t = 10%, 7% and 5%).](image)
ducer surplus. ES that are valued by estimating a demand curve (stated and revealed preferences, hedonic methods) can also be marginally measured, but these methods are more demanding, both methodologically and in terms of data.

Our study has provided some clear inputs for this production function, by demonstrating empirical MPA impacts on fishery ES. Results are derived from a relatively time consuming regime with a program of experimental fishery, control-impact approach and RCA statistical analysis. Results showed an increase in productivity for the principal gear, estimated to vary from 6% to 33% increase in the CPUE in Vanuatu, similar to findings of the few other available studies (Russ and Alcala, 1998). Even if variation is substantial (five fold between minimum and maximum CPUE increase) and more empirical studies are necessary, these results should provide a base for other MPA studies through benefit transfer, or through calibration of the many existing bio-economic fishery models. Other observed effects were not valued, such as: (i) less variability on fish harvest per trip (Cote et al., 2001) and, (ii) larger-sized fish caught for villages with MPAs (Halpern and Warner, 2002).

For tourism, results were derived primarily from surveys with end-users to determine the role of the MPA and marine attributes enhanced by MPA in their choice destination. The range of factors was high (between 10% and 70%) and reflects the variability of the tourism context faced by MPAs. The ecological attributes and/or the presence of the MPA will have different weights in the motivation of tourists to visit the sites. In Vanuatu, the tourism context is a small-scale accommodation sector attracting primarily a “nature-tourism” segment, for which MPAs represent an important attraction. In Saint Martin, with a mass tourism sector based mainly on the model of the 3Ss (Sea, Sand and Sun), the MPA and/or ecological attributes of the site (e.g. scenic beauty and the presence of emblematic species) do not appear to be an important aspect of tourism attractiveness. In both cases, the MPA impact on the tourism ES was the most important in monetary terms. This importance highlights the weight of this relationship between MPAs and tourism linked to nature.

Even though it is important to bear in mind the difficulty of isolating any factor in the selection process of the destination by tourists (Tourism and Transport Consult, 2005, Parry and McElroy, 2009), the approach of determining the MPA factor through end-user surveys has provided some clear insight about this MPA impact.

4.2. Spatial boundary of analysis

The spatial boundary has rarely been discussed systematically and specifically in the reviewed CBAs (François and Pascal, 2012). Most studies define and delimit the ecosystem being studied, and some explicitly limit their analysis to the local communities and areas directly interacting with the ecosystem (“local” economy), but these limits generally do not coincide with the area impacted by the ecosystem processes, nor the economic jurisdiction (Balmford et al., 2008). Several authors concur that spatial understanding of ES is a key variable in the implementation of the majority of economic instruments (Balmford et al., 2008). Indeed, identification of areas where the processes required to generate ES are central to accurately improve their management. For example, the larval dispersal and migration areas of key species for fishing, or as dive attractions are often not in the same location as the fishing grounds and dive sites (Kinlan et al., 2005). Similarly, the site where the added value of fishing and tourism is generated, may be different from the area where the benefit is found (residence tax, pre-paid package tourism, etc.) (Burke et al., 2008). However, appropriate policy formation based upon spatially explicit economic values is rife with theoretical and empirical limitations. Considering the complexity of these processes (variability and importance) and the technical challenge in identifying the flows of dispersion of marine species (Sale et al., 2005), economists will need to use proxies and make simplified assumptions in order to most efficiently affect individual human behavior toward social objectives.

4.3. Advocacy

The results of this study have provided information which can be used by decision-makers regarding investment in marine reserves as a conservation and development tool for local populations. Our findings are complementary with the few peer-reviewed papers on the subject of CBAs in the domain of coral reef economics. One study using a similar approach, was conducted by White et al. (2000) in Olongo island, Cebu (Philippines) and showed a very strong justification on the part of local and national government and private sector groups to invest in the management of reefs to generate current annual net revenue ranging from US$ 38,300–63,400 per km². Another similar approach was provided by Cesar and Chong (2006), who assessed the economic interest in establishing a MPA in Portland Bight Area (Jamaica). The authors found a total (incremental) benefit estimated around US$ 40.8 million (in the pessimistic tourism case), hence justifying the US$ 19.2 million costs involved in the MPA implementation over 25 years. Calculating the financial benefits based on the size of the Jamaican MPA, shows a rough figure of US$ 21,700 per year per km². Though slightly greater, our key-figures ranging from US$ 30,000 (Saint Martin) and US$ 44,000 (Vanuatu) per km², are still consistent with all these findings.

Most other CBAs for coral reef management are found in the grey literature. For example, studies in South Africa and Vietnam found Net Present Values of MPAs, estimated at US$ 10.4 million (Turpie et al., 2006) and US$ 18.9 million (Nam and Beukering, 2013), respectively. However, these results are difficult to link with our single MPA figures. Other CBA reports significantly differ from our objectives as they focus on analysing other management options. For example, Fahrudin (2003) looked at the economic effect of reducing coral threats (cyanide and coral collection) in Indonesia, while Beukering et al. (2007) analysed the management options of six MPAs in Hawaii, and Clarke et al. (2010) assessed the cost and benefits of a zoning extension of a marine park in Australia.

It may be important to complement the CBA with more specific indicators about effectiveness for nature conservation (Tallis et al., 2010). In our case we relied on areas of protected reef as an indicator of conservation, but other studies have demonstrated that MPAs are not a “silver bullet” for all marine conservation issues (Boersma and Parrish, 1999).

To our knowledge, the juxtaposition of measures of local financial returns (RoI) and of broader economic measures of project net benefits (BCR) to bridge the gap between incentives for local stewardship on one hand and total economic value on the other, has been used infrequently in the environmental economics scientific literature. By comparing it with the BCR, the indicator RoI provides less complete information, not including benefits absent from markets (ES3 to 5) as well as opportunity costs. The RoI was intended to highlight the cash flows for the local economy, in addition to fisheries and tourism, which represent both concrete sources of local cash incomes and implicit income through harvested food-stuff. Focusing on flows of observable impacts and avoiding the projections bias, it may complement the BCR with results that are easier to understand or accept. Financial decision-makers (e.g. public finance), accustomed to the CBA and RoI tools (Arrow et al., 1996) may feel more comfortable basing their budget allocation tradeoffs on both results. As highlighted by other authors (de Wit et al., 2012) it is important to prove that public investments in
natural assets provide yields with adequate returns, as does investment in other infrastructure and services, such as housing and education.

In parallel, the BCR and RoI financial approach may bring concrete information about potential returns for private sources of financing for conservation (Parker et al., 2012). In the case of the impact investment funds (Achleitner et al., 2011) or the Socially Responsible Investment (SRI) funds (Van den Bossche et al., 2010), where capital is invested with the explicit expectation of financial, social and environmental returns, the Internal Rate of Return (IRR) and the RoI are common indicators for investment selection (Littlefield, 2011). Many requirements for viable and effective investment of this type are still necessary (conservation market institutions, quantifying benefits, business models, accounting and auditing standards) (Miteva et al., 2012) and this work is an initial step in this new field.

5. Conclusion

The study has provided some insights into the trade-offs between a pressing need for informed decision making on the environment and the requirement for extensive empirical studies on MPA impacts. As we have shown, CBAs have demonstrated both promising results and significant limitations. Results can be sensitive to the uncertainties and knowledge gaps regarding MPA impacts on ES, however CBAs of environmental investments (such as MPAs) are complex exercises and methods must still be consolidated. There is a need to improve the ecological knowledge base in relation to CBAs, such as the requirement to address the links between investment, ecosystem processes and ecosystem services. This study has proposed several approaches for the valuation of these links with the ES of fisheries and tourism. It also showed evidence that the selected MPAs produced benefits for local stakeholders through their impacts on ES; commercial and subsistence fishermen (through impacts on ES1), tourism businesses (ES2), landowners (ES3), local populations (ES4 and ES5) and the international community (ES6) all benefited from the establishment and management of these MPAs. The evidence of local benefits and their distribution patterns has been recognized as a way of increasing the explicit expectation of economic, social and environmental returns, which may be attracted by some aspects of the benefit-cost ratios for MPAs, since it could make the business case for coral reef conservation.

In addition to strengthening support from policy makers, these results also show a potential basis for the establishment of exploratory marine PES, by helping in the identification of the beneficiaries of improved marine ES (Engel et al., 2008). Clear values of ES and impacts of investment can serve to “fine tune” the instrument in negotiations between providers and buyers (The Katoomba Group and Marketplace, 2010). In parallel, the private financing of conservation with innovative tools such as impact investing funds (Littlefield, 2011), where capital is invested with the explicit expectation of economic, social and environmental returns, may be attracted by some aspects of the benefit-cost ratios for MPAs, since it could make the business case for coral reef conservation.

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