Valuing aggregated ecosystem services at a national and regional scale for Vanuatu using a remotely operable, rapid assessment methodology

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Abstract

There is now an established interest and a clear case for using economic valuation of ecosystem services to inform a range of policy issues and questions. However, access to both habitat data and economic valuation for less developed countries is limited, despite these communities relying acutely and directly on ecosystem services. Here we set out an ecosystem assessment methodology that employs GIS data and benefit transfer studies, which can be carried out remotely and rapidly and at multiple scales. We use two case studies: Vanuatu, in the south west Pacific Ocean and one of its less developed islands, Tanna. These case studies reveal the value of ecosystem services to communities is considerably larger than income reported through traditional national accounts, suggesting that policies that support sustainable exploitation of these services and conservation of natural capital are paramount in securing human and community well-being.

1. Introduction

There is now an established interest and a clear case for using economic valuation of ecosystem services to inform policy-making, compensation claims and—increasingly—to reduce corporate risk through full cost accounting (Kumar, 2010; Costanza, et al., 1997; Barbier, 2012; Sinner, Bell, Phillips, Yap, & Batstone, 2016; Arrow, et al., 1993; Natural Capital Coalition, 2016). Although the importance of ecosystems to human welfare has numerous dimensions (ecological, socio-cultural and economic), expressing the value of ecosystem services in monetary units is an important exercise in framing options between different policy options, compensation claims, and forms of investment; “[a]s long as we are forced to make choices we are going through the process of valuation” (Costanza, et al., 2017, p. 7). Such exercises help to reveal the most socially-efficient options, raise awareness and convey the (relative) importance of ecosystems and biodiversity to policy-makers, business and civil society, which may otherwise have been discounted or not considered at all.

The majority of published studies focus on marginal changes in the value of a narrow band of ecosystem service flows from a single ecosystem type in a tightly defined geographic area, which in turn is employed in exercises in benefit cost analysis of a specific policy or project proposal. However, from a policymaker's perspective, what is also often required is a broader valuation of aggregated ecosystem service flows from a particular ecosystem, or the total value of all ecosystem service flows within a particular area, such as a politically defined geographic boundary (e.g. country, state or province). Such broad-spectrum, aggregated valuations, which can be referred to as 'Total Ecosystem Service Value' (Kubiszewski, et al., 2017), are useful in a range of applications, including: when considering the implications of national- or landscape-level trends in ecosystem service benefit flows as a result of extraneous factors, such as climate change; in assessing policy trade-offs involved in macro land-use change proposals; determining appropriate price envelopes for payments for ecosystem service schemes; revealing dependencies on ecosystem services to reveal community vulnerabilities to environmental and social change; and when prioritising program-level interventions in a development context, where reliance on ecosystem services for immediate provisioning needs, such as food and *materiale*, is direct, immediate, and significant. These applications are given heightened importance in communities where the contribution of ecosystem services to national income may considerably outweigh that of published national accounts[1].

The purpose of this paper is to describe a rapid and cost-effective methodology that can be carried out remotely by a multi-disciplinary team. It employs Geographic Information System- (GIS-) based ecosystem mapping, coupled with ecosystem service economic valuation methods, in determining and valuing ecosystem service benefit flows at a regional and national scale. As a case study, we use the Republic of Vanuatu, a Melanesian archipelago in the south west Pacific, and also one of its less-developed islands, Tanna.

Habitats across Vanuatu and Tanna are under pressure from a range of local and global ecological and socio-economic factors, including: climate change, which has the potential to alter microclimates and crop growth envelopes; high fertility and population growth putting pressure on forests and fringing reefs; and poor and falling yields from the predominant small-scale subsistence gardens. At the same time, on Tanna, there is potential for rapid cultural and socio-economic dislocation as island's economy begins to transform from village-based agrarian subsistence towards a more market-based, monetised system, with a focus on cash-cropping and tourism. Therefore, data to support decision-making on a macro-scale is important to ensure ecosystem services are transparently valued and the needs of rural communities is considered.

2. Case study context: Vanuatu and Tanna

The Republic of Vanuatu is an island nation in the south-western Pacific Ocean, approximately 1,750 kilometres (km) east of Australia. It is linear archipelago of recent volcanic origin, comprising 83 islands (65 of which are inhabited) spanning nearly 900 km and 7 degrees of latitude. The land area is approximately 1,227,337 hectares (ha) and its coastline is 2,528 km long. Shorelines are mostly rocky, with fringing coral reefs but no continental shelf. Many of the islands are steep, with fertile, but unstable soils and little permanent fresh water.

[1] For example, in Constanza, et al. (1997) the authors argue this situation is common to the entire planet – the value of ecosystem services is significantly larger than the global GDP.

Vanuatu's population is 270,402, with an annual growth rate of around 2.2% (double the global mean) and a (relatively young) median age of 20.5 years (Vanuatu National Statitics Office, 2009). The national government is heavily dependent on foreign aid for infrastructure investment and domestically Vanuatu is highly reliant on nature-based tourism, offshore financial services (it acts as a tax haven), and the export of coconut products. Broader economic opportunities are and employment specialisation is limited and the majority of the population relies on subsistence farming for their livelihood, with 75% of the population living in rural areas and more than 98% undertaking some form subsistence gardening. (Vanuatu National Statitics Office, 2009). Given Vanuatu's relative proximity to important consumer markets and its offerings in nature-based tourism, growth in this sector remains relatively poorly developed compared to Fiji and New Caledonia, as air connections remain poor and beyond the two economically importantly islands (Efate and Espiritu Santo) road links remain slow and laborious. As a result, tourism ventures in other parts of Vanuatu are predominantly small-scale, locally-run establishments, which merely supplement the owners' well-being with cash incomes.

Tanna is in the southern Vanuatu province of Tafea. It covers 58,793 ha and has a population of 28,799[2]. Unique to Vanuatu, seven different indigenous languages are spoken on the island, in addition to some people who also speak Bislama, the national language. Many of the tribes on the island live in traditional housing and Tanna is often referred to as the stronghold of 'kastom' – a place where people still know traditional songs, can trace their lineage, and still organise and participate in kastom rituals and ceremonies. Most of the tribes on Tanna still follow kastom ceremonies to a large extent, for example for funerals and weddings (Lindstrom, 1982; 2011). The traditional calendars are still used to signal particular activities such as planting of the yam and its harvest, and associated ceremonies. Tanna is regarded as an example of how kastom and modernity can coexist. As a result of poor local transport connectivity and no direct international flights, tourism development has been slow, comprising both formal and informal, mostly family-run operations.

Currently, most of the population on Tanna depend on subsistence farming, fishing, and wild food and non-food harvesting (for building, for example) for their livelihoods, although a small number of people are engaged in small-scale tourism services and in service industry jobs, such as operating small retail outlets and provision of goods to tourism operators. In addition, remittances are sent by relatives who take employment in Port Vila (the nation's capital) or overseas. Rapid population growth is exerting pressure on the environment but alternative cash income opportunities could potentially reduce this pressure, providing access to alternative food markets.

[2] However, the current number is possibly considerably higher, given rapid population growth. For example, during government disaster recovery and food relief operations after 2015 Tropical Cyclone Pam, 44,000 people were reported as residing on the island.

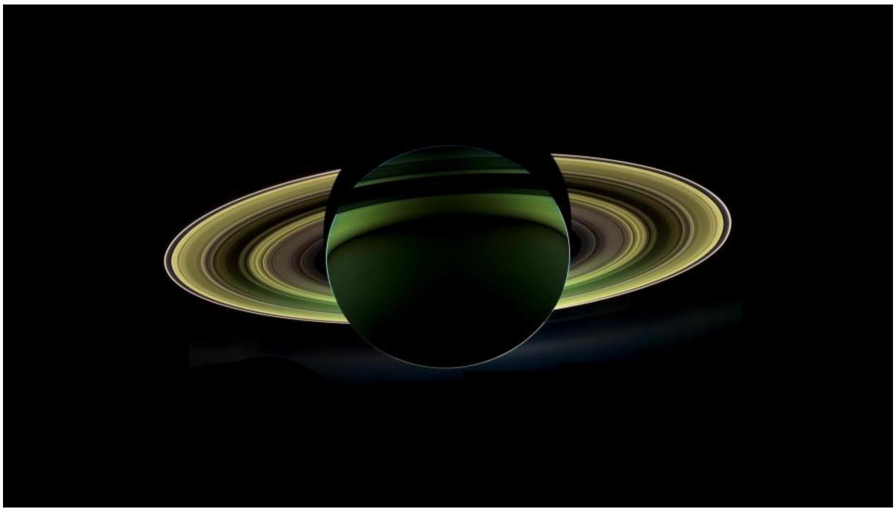

Figure 1: Map of the Vanuatu archipelago, showing the location of Tanna

3. Conceptual framework

In implementing the GIS-mapping and economic valuation exercise, we draw upon the conceptual framework developed by the U.N. Statistical Commission's Experimental Ecosystem Accounting system (European Commission, OECD, United Nations and World Bank, 2013), which describes ecosystem accounting as a coherent and integrated approach to the assessment of the environment through the measurement of ecosystems, and measurement of the flows of goods and services from ecosystems into economic and other human activity. The system notes the spatial scale of ecosystem accounting may vary from specific land cover types, such as tropical forests, to larger integrated areas, such as river basins, and includes areas that may be considered relatively natural and those that may be heavily influenced by human activity (subsistence gardens, for example). According to the Commission's system, ecosystem accounting goes beyond other approaches to ecosystem analysis and assessment through the explicit linking of ecosystems to economic and other human activity. The links are seen both in terms of the services provided by ecosystems and also in the impacts that economic and other human activity may have on ecosystems and their future capacity to continue to deliver ecosystem service flows.

A key term the Commission introduces is 'ecosystem assets', defined as spatial areas containing a combination of biotic and abiotic components and other characteristics that function together[3]. Ecosystem assets are measured in terms of ecosystem *type*, *extent*, *condition* and *services*. These assets generate a particular combination, or 'basket', of potential ecosystem service benefits to people; 'potential', as there can be no assumption the ecosystem service will be exploited. Importantly, ecosystem service benefits do not result only from the harvesting and extraction of materials from ecosystems – i.e. provisioning of goods and services. They also result from the general functioning of the ecosystem (e.g. air filtration services from trees in providing clean air) and extend to other characteristics of an ecosystem (e.g. the physical structure of a composition of mountain landscapes providing scenic views). Thus, the term 'services' is used here in an all-encompassing manner, covering various ways in which humans may benefit from ecosystems.

[3] The term 'natural capital' is now also widely used to describe the stock of bio-physical assets from which ecosystem services flow.

In addition, we employ the framework of ecosystem service categorisation developed by the Millennium Ecosystem Assessment (MEA) (2003) and further developed by de Groot, et al. (2012). Ecosystem services are grouped in four broad categories: (i) *Provisioning* – the products used by humans that are obtained directly from habitats and ecosystems (e.g. wild fish and timber); (ii) *Regulating* – the benefits obtained through the natural regulation of ecosystem processes (e.g. air quality and climate regulation); (iii) *Habitat* – the provision of environmental services (e.g. nursery services and genepool protection); and (iv) *Cultural* – the non-material benefits people receive from habitats and ecosystems (e.g. recreational enjoyment and cultural connection). Taking both MEA'a and de Groot, et al.'s (2012) () schema further, we modified these categories to add the specific context of Tanna's customary governance of habitats, to include kastom services (or 'governance services' (Sarkki, 2017)) in Table 1.

Table 1: Classification of ecosystem services as conceptualised by Experimental Ecosystem Service Accounts (UN, 2012) and modified to include kastom services

Table contents here.

4. Ecosystem assessment

Ecosystem assessment involves gathering data regarding the *type*, *location and extent*, and *condition* of ecosystems in a format suitable for informing decision-making. The quantity, quality and the potential beneficiaries of the flow of ecosystem services is a function of these attributes. All these ecosystem attributes are throughout Vanuatu are under pressure from multiple anthropogenic influences, local and global, including climate change impacts (general warming and extreme weather events), increasing demand for natural resources from population growth and increasing wealth, and stubbornly low productivity of the subsistence gardens. Ecosystem assessments were conducted at both the national (Vanuatu) and island (Tanna) scales.

4.1. Ecosystem types

To map ecosystem types, it is first necessary to classify them. While terrestrial ecosystems can be identified and mapped using various criteria, from a practical perspective (and in a Melanesia context) they have been defined here according to the major vegetation types that have been recognized by various biodiversity and forest surveys (Munzinger, Lowry, & Labat, 2012). In addition to terrestrial categories, we recognized the general marine coastal ecosystem categories of 'coral reefs' and 'sea grass'. The summary of ecosystem types are in Table 2. A comprehensive qualitative description of these ecosystem service types is provided in Mackey, et al. (2017, pp. 6-10).

Table 2: Vegetation types in Vanuatu (Munzinger, Lowry, & Labat, 2012; Mackey, et al., 2017).

Table contents here.

In this case study, we also included 'subsistence gardens' and 'plantation forests' as ecosystem types. In Vanuatu, small-scale subsistence food production to some extent is undertaken by 98% of the rural population (Vanuatu National Statistics Office, 2012) and is thus a significant land-use. These subsistence production systems typically comprise three components: (1) a shifting cultivation system; (2) a perennial plantation cultivation system; and (3) a forest and aboricultural system (Blanco, Pascal, Ramon, Vandenbroucke, & Carriere, 2013; Clarke & Thaman, 1993). In the shifting cultivation component (that most closely related to traditional subsistence gardening) each family slashes and burns secondary forest in two to five locations per year to grow taro and yam. Then having depleted the soil's fertility, the family leaves it fallow, allowing for secondary regrowth to start the cycle again (Mackey, et al., 2017). The traditional shifting cultivation crops of taro and yam are today being supplemented by recently introduced peanuts and sweet potato. The perennial cultivation system constitutes the main source of cash income for families; mostly growing coconut, cacao, coffee and sandalwood. Large trees are often left or new productive fruit/nut trees planted for their economic and cultural value. The intimate, inter-dependent and cyclical relationship between rotational subsistence gardening, perennial planting, secondary tropical forest regrowth and use of forest products demands that the categories of subsistence gardens and plantation cropping are included as an 'ecosystem' type in this assessment.

4.2. Ecosystem extent, location and condition

4.2.1. National terrestrial ecosystem assessment

The vegetation classification and maps of Schwetter (2012) determines a combination of vegetation type, vegetation condition and land-use. The author's maps comprise polygons in .shp file format, which continuously cover Vanuatu's terrestrial environment, with associated classification of vegetation type, condition and land-use. We endeavoured to separate out these variables by producing two separate GIS data layers of (i) ecosystem type; and (ii) ecosystem condition. To assess the condition of the terrestrial ecosystems we used a modified version of the Vegetation Assets, States and Transitions (VAST) method developed by Thackway and Lesslie (2006). A summary and sample application of the VAST method is in Table 3. Our primary source of information on ecosystem condition was the Schwetter (2012) vegetation maps, which provided an assessment of areas of forest and thicket considered as degraded or intact. Unfortunately, we determined there was insufficient data at the national level to undertake a conclusive or robust assessment of the condition of Vanuatu's terrestrial ecosystems. Based on the published literature it is likely the available mapping over-estimates the proportion of ecosystem types that are in an 'intact' condition and there is, for example, probably more shrub and thicket in a modified state.

Table 3: Categories for condition of land cover in Vanuatu and sample applications (Thackaway & Lesslie, 2006)

Table contents here

Whilst there are numerous possible classifications available for ecosystem service types, with an eye on the economic valuation of ecosystem services step of our overall methodology and assessment, we adopted a classification that was consistent with that used within the ecosystem service valuation literature (de Groot, et al., 2012; van der Ploeg & de Groot, 2010), often referred to as 'biomes'. Our adjudged alignment with the Vanuatu terrestrial vegetation maps from Schwetter (2012) is in Table 4.

Table 4: Aligning Vanuatu vegetation maps (Schwetter, 2012) with ecosystem service condition (Thackaway & Lesslie, 2006) and biome type (de Groot, et al., 2012).

Table contents here

4.2.2. National marine ecosystem assessment

To determine the location and extent of coastal marine ecosystems, we used GIS data layers generated from global inventories of coral reef (UNEP/WCMC, 2017a) and sea grass (UNEP/WCMC, 2017b).

The condition of coral reefs was modelled based on an empirically established relationship between reef condition and the density of human populations in the coastal zone. This strategy for estimating ecosystem condition via a metric based on available data is particularly relevant for marine habitats as costs preclude broad scale direct assessments and remote sensing techniques cannot at this stage estimate condition reliably. While to some extent the science underpinning the use of proxy metrics to indicate ecosystem condition is still developing, for coral reefs it is widely accepted there is a negative relationship between ecosystem condition and proximity to human populations. The deleterious effects of humans on coral reefs are largely a result of land-based pollution and the cascading trophic effects of harvesting of fish, invertebrates and turtles. The results from field studies have highlighted the importance of several potential indicators relating human proximity to reef condition, including coastal population density, socio-economic status of populations, distance from population, and travel time from population centres to reefs (Brewer, et al., 2012; Cinner, et al., 2003; Maire, et al., 2016). Where fishing is for-profit (rather than subsistence), distance to market is another measure that can be used to predict reef condition (Brewer, et al., 2013). However, it should be noted one recent global analysis could *not* find a predictive relationship between human populations and reef condition (McClanahan, et al., 2011). The authors suggest two principal reasons for the apparent lack of a clear relationship: (i) the different intensities of fishing practices in different locations, from small-scale subsistence fishing to large-scale, industrialised harvesting; and (ii) natural variation in measures of coral reef health among different biogeographic provinces. In Vanuatu, however, we consider the use of a human proxy to be valid as the range of fishing practices is narrower than that occurring globally and reefs are all in the same biogeographic region.

For Vanuatu, we were able to access reliable, spatially-explicit data on human populations from national census surveys (Vanuatu National Statitics Office, 2009). For the entire coastline of the country we calculated population density (persons per km^2) in a 1-km wide strip, based on 10 km grid cells and categorised into three levels of impacts following the principles in Table 5. However, note that for coastal assessments the 'Transformed' category typically represents a higher level of impact on condition than 'Modified', but does not imply that an alternative habitat is present.

Table 5: Coral Reef condition assessment classification

Table contents here

To establish the relationship between an area of coral reef and population density, GIS analysis was used based on the following steps:

(1) The input datasets above were imported to Arcmap.

(2) A buffer zone was created 1km landward of the shoreline for all of Vanuatu.

(3) Households outside the coastal buffer zone were discarded from the population density calculations.

(4) A 10 km^2 fishnet (regularly spaced grid) was created over Vanuatu.

(5) Population density or number of people per km^2 was calculated for each grid cell.

(6) A frequency histogram of population density was prepared. There is a spread of population densities from zero to greater than 100 and these group approximately evenly into the three categories of population density. Categories of population density were assigned based on frequency across three categories (people per km^2): Low (0-10); Medium (11-50); High (>50).

(7) Condition was allocated to the reef within a given grid area based on the population density category as described in Table 6.

The results of the coral reef ecosystem assessment (extent and condition) is in Table 6.

Table 6: Coral reef ecosystem assessment for Vanuatu (extent and condition).

Table contents here

4.2.3. Tanna level ecosystem assessment

To demonstrate how this rapid assessment methodology can be augmented by more detailed field work, we undertook on-ground ecosystem type identification work on Tanna. Therefore, our ecosystem mapping of Tanna drew on national level data complemented by satellite image classification, field survey observations and digital terrain analysis. We employed the same terrestrial ecosystem classes developed for the national assessment, however, we remapped the extent of the ecosystems using a new land cover map for Tanna based on a high-resolution mosaic of RapidEye satellite imagery compiled by the authors. The most recent cloud free images were used, noting that due to almost continuous volcanic activity the southern part of the island is rarely cloud- or ash cloud-free.

The following process was used for the type and extent maps for terrestrial ecosystems:

(1) A combination of field visits to Tanna and review of satellite imagery was used to compile a dataset of ecosystem types for more than 100 sites across the Island representative of different ecosystems.

(2) RapidEye multispectral satellite imagery was used within the TerrSet application to segment polygons across Tanna, based on homogeneity of the spectral pattern providing more than 1,000 polygons for the island.

(3) For the areas of Tanna where the volcano smoke or cloud obscured the RapidEye image, a fishnet was created with grid cells of $500m^2$ creating approximately a further 1,000 polygons.

(4) The RapidEye segments and the fishnet were combined into a single continuous layer of polygons covering the entire terrestrial area of Tanna.

(5) Where a field site fell within a polygon, that polygon was classified as the ecosystem recorded by the field site.

(6) The remaining unclassified polygons were imported to Google Earth and overlaid on high resolution satellite imagery of Tanna.

(7) Each of the unclassified polygons were allocated an ecosystem type, based on knowledge of the island and judgement on the nature of the ecosystem from a Google Earth satellite view.

(8) Coral reef extent drew on the 2010 Global Coral Reef Distribution map from the national assessment (UNEP/WCMC, 2017).

Note that based on extensive field surveys, the coastal mangrove and coastal seagrass ecosystems were found only in very small areas on Tanna and therefore were not included in the ecosystem assessment for Tanna.

4.3. Ecosystem assessment summary

The ecosystem type and extent (and relative proportions) for the national level and Tanna level are summarised in Table 7.

Table 7: Ecosystem type and extent for Vanuatu and Tanna Island.

Table contents here

5. Economic valuation

With ecosystem type, location and extent and—for coral reefs—condition determined, the next stage of the methodology is estimate the flow of ecosystem services from these ecosystems. The methodology set out here is designed as a response to the general paucity of primary data on localised or contextualised ecosystem service valuation, particularly in least developed countries. This is a function of the expense and logistical difficulty (but also perhaps of lack of academic interest) in accessing communities to undertake relevant research. Therefore, our methodology reflects the conditions under which many landscape level ecosystem service valuations are carried out, in both academia and consultancy, in less developed countries. In the absence of appropriate datasets or the financial backing to venture into the field researchers and practitioners are forced to employ alternative methods of sourcing data; namely the 'benefit transfer' approach.

The benefit transfer approach is a method of estimating the economic value of an environmental good or service at a *target* site using information from an existing study (or studies) conducted at another *source* site. In practice, benefit transfer typically involves searching the relevant published literature to identify existing studies that value ecosystem goods or services that have similar social and biophysical contexts to those in which the researcher is interested. For example, if the objective of the study is to estimate the value of subsistence fishing from a coastal coral ecosystem in a target area, researchers can apply values from studies undertaken under similar socio-economic conditions. Note that the value of commercial recreational fishing in a developed country would be an inappropriate source site study in this case. When using a benefit transfer approach, in the absence of a single highly relevant study, it is prudent to use the median value derived from as many appropriate studies as time permits discovering.

5.1. Relevant studies for benefit transfer

The most comprehensive analysis of ecosystem service values published to date is that of de Groot, et al. (2010), where the authors collate and assess 665 studies obtained from The Economics of the Environment (TEEB) Valuation Database (van der Ploeg & de Groot, 2010). Of the assessed and appropriate studies from this database only three related directly to the Pacific Islands – caution, therefore, is needed in interpreting the values derived from their analysis for Vanuatu and Tanna. This database provides monetary values for 12 'biomes' and 38 ecosystems, which in this report we simply refer to as 'ecosystem types' that we mapped to Vanuatu and Tanna ecosystems (Table 4): coral reefs; coastal mangrove, coastal seagrass, freshwater wetlands, freshwater water bodies, tropical forests, grassland, subsistence gardens and plantation cropping. For each ecosystem type, 22 ecosystem services are taken into account (see Table 1), following TEEB classification (van der Ploeg & de Groot, 2010).

Alternative sources to de Groot, et al. (2010) and van der Ploeg & de Groot (2010) were employed where there were Vanuatu-specific studies and reports available from a literature search ((a) below) or where no appropriate studies could be found for particular ecosystem types and/or ecosystem service flows in the database ((b), below).

(a) Pascal and Bulu (2013) provide an economic valuation of mangroves as part of the IUCN Oceania Mangrove EcoSystems for Climate Change Adaptation and Livelihoods (MESCAL) project. In this study, the authors use a combination of desktop research and field studies to determine the cultural and commercial uses of mangrove resources at Crab Bay (Malekula Island) and Eratap (Efate Island). The authors present economic valuations for nine ecosystem services (subsistence fishing, commercial fishing, recreational fishing, coastal protection, tourism, wood extraction and carbon sequestration), which were adapted and inserted into the classification scheme set out in Table 1.

(b) For coral reefs′ contribution to erosion prevention we derived per hectare values from Pascal, et al.′s 2015 report on the Economic Assessment and Valuation of Marine Ecosystems: Vanuatu. The authors evaluated coral reefs′ contribution to erosion prevention for the islands of Efate (separate east and west coast values were determined), Espiritu Santo and Malekula, using the avoided damage cost method. As Vanuatu′s emerging tourism sector is concentrated on Efate and (to a lesser extent) Espiritu Santo, these islands host high value property and infrastructure, such as hotels and airports, which are of considerably higher value than that of property on Malekula, where no hotel infrastructure was identified. In addition, as Malekula′s settlement pattern was judged to be similar to that of the majority of coastal Vanuatu, the Malekula-derived value for coral reef′s contribution to erosion prevention was considered the most representative for Vanuatu at the national scale[4].

5.2. Valuation method

For our nine ecosystem types we used in-built filters from van der Ploeg and de Groot′s (2010) database to isolate appropriate economic valuations for our 22 ecosystem services (Table 1) for our 9 ecosystem types (Section 5.1). In employing the filters we:

(1) removed studies that were conducted in high income countries on the basis that the primary benefits derived from ecosystem services in these countries (e.g. recreation) bear little resemblance to the primary benefits derived from ecosystems services in developing nations, such as Vanuatu;

(2) removed studies that applied only to population density areas, on the basis the relatively higher property values and the intensity of economic activity in these studies does not reflect the predominantly rural, subsistence setting of Vanuatu;

(3) excluded the more generalised criteria of ′World′ from the column 'Country', to exclude contamination from more generalised economic valuations;

(4) removed known specific anomalous studies that were significantly influenced by a single substantial value, such as that for tropical forest medicinal resource values where we discounted the value assigned by Yaron (2001) to the bark of a

[4] Though it should be noted that future development of the tourism sector across Vanuatu as a whole will entail an increase in the value of coral reef contribution to erosion control.

locally endemic tree species in Cameroon that has an established (very high) market value as a medicinal treatment for prostate cancer;

(5) adjusted the 2007 international dollar values reported by van der Ploeg & de Groot (2010) to report values in 2015 US$ (when the field work in Tanna was completed).

In all of the economic values where we discovered more than a single value we employ the median value, rather than the mean, as the median is less likely to be influenced by a small number of outliers. A valuation for kastom services was not included, as it is likely this value is highly-specific to Vanuatu and, perhaps, further-specific to Tanna and therefore not appropriate for a benefits transfer approach.

Table 8 shows the output of our approach.

Table 8: Calculated value of ecosystem services by ecosystem service type for Vanuatu (2015 US$ ha^{-1} yr^{-1}).

Table contents here

The final step is to employ the derived per hectare per year ecosystem service values from Table 8 to calculate an estimated monetary value for each of the nine ecosystem types for each ecosystem service flow for Vanuatu and Tanna, based on the area of each ecosystem type from Table 7. This output is the *Total Ecosystem Service Value* (TESV) for Vanuatu and Tanna and is detailed in Section 6 and Table 9.

6. Total ecosystem service values for Vanuatu and Tanna

The value of Vanuatu's ecosystem services to human society is considerable, delivering more than US$ 10 billions of value per year (see Table 9). By comparison, Vanuatu's gross domestic product for 2015 was US$ 742 million; smaller by a factor of 13½. Approximately 98% of Vanuatu's ecosystem service value derives from three ecosystem service types: coral reefs (57%), tropical forests (26%), and subsistence gardens (15%).

Table 9: Total ecosystem service value for Vanuatu (2015 US$ yr^{-1}).

Table contents here

Table 10 shows how ecosystem services are potentially captured by the people of Vanuatu. Approximately 69% is provided through three ecosystem services: genetic resources (27%), raw materials (26%), and food (16%). This reflects the significance of provisioning ecosystem services (70%) for Vanuatu. Regulating services contribute 22% of the total, habitat services 6% and cultural services 3%. The full breakdown of ecosystem services is in Table 10.

Table 10: (Potential) Ecosystem service benefit by ecosystem service type (US$ yr^{-1}).

Table contents here

Similarly, the value of ecosystem services to Tanna is also considerable: US$ 518 million per year (Table 11). (Comparisons with Tanna's regional product are not possible, due to lack of data, but is likely to be considerably larger than the multiplier for Vanuatu.). Similar to the Vanuatu national scale values, Tanna receives the vast majority of ecosystem service benefit from coral reefs, subsistence gardens and tropical forests (99%).

Table 11: Total economic service value for Tanna (2015 US$ ha^{-1} yr^{-1}).

Table contents here

Table 12 shows how ecosystem services are potentially captured by the people of Tanna. Approximately 81% is provided through three ecosystem services: food (45%), genetic resources (18%), and raw materials (18%). This reflects the significance of provisioning ecosystem services (81%) for Tanna. Regulating services contribute 14% of the total, habitat services 3% and cultural services 1%. The full breakdown of ecosystem services is in Table 12.

Table 12: Total ecosystem service benefit by ecosystem service type for Tanna (2015 US$ yr^{-1}).

Table contents here

7. Discussion

This study has set out a rapid and remotely operable methodology for assessing the ecosystem service contribution to the well-being of communities within defined boundaries, which is particularly useful in remote or developing country contexts, where access is difficult and data is scarce. Valuation of ecosystem services flows can provide useful information to assist communities, planners and policy-makers in gaining a more comprehensive understanding of the relative benefits that arise from protecting and restoring ecosystems; the contribution ecosystem services make to sustainable livelihoods of communities, as well as national accounts; the costs that can be avoided when inappropriate developments and unsustainable uses degrade ecosystem condition; and the trade-offs that need to be considered when designing policies, interventions and community development programmes. This approach taken here is consistent with Section 2.2 of 'The Brisbane Declaration on Ecosystem Services and Sustainability in the Oceania Region' (Oceania Ecosystem Services Forum, 2017), which encourages technical and methodological support (amongst other things) to ensure environmental-economic accounting is multi-scale, multi-stakeholder and provides consistent methods data collection and a framework to link outputs to decision-making; assess trends in environmental asset; and provide technical expertise in mapping and spatial information.

Our assessment is a 'snapshot' of the value of ecosystem service benefits at a specific point in time. Understanding longer term trends in ecosystem service benefits under different scenarios for Vanuatu/Tanna. For example, the 'Great Transition Initiative' described four archetypes that describe a range of plausible futures on a global scale. These scenarios have been used by Kubiszewski, et al. (2017) as a basis for calculating changes in total (global) ecosystem service values over the period to 2070[5]. Whilst in this instance the scenarios are 'exploratory', rather than 'target-seeking' or 'policy-screening', similar models can be generated for more localised contexts, such as Vanuatu and Tanna, in consultation with local policymakers and communities, for the purposes of policy assessment, particularly

[5] Similar broad-based socio-economic/biophysical models are also used by IPCC in the Representative Concentration Pathways

in light of the global, cross-sector drive towards achievement of the Sustainable Development Goals[6].

Demonstrating the monetary values of ecosystem services that have potential to raise revenue through PES schemes, such as utilising the carbon sequestering capabilities of tropical and mangroves, can also assist least developed countries plan to help communities capture value from natural capital stocks, which may otherwise become degraded through neglect of common pool resources or pursuit of development and economic patterns that are incompatible with localised sustainable development.

7.1. Reflections on case study sites

Whilst the primary purpose of the paper is to describe a pragmatic and defensible methodology, it remains worthwhile to reflect on what the methodology revealed about the case study sites of Vanuatu and Tanna. Overall, the ecosystem service valuations emphasise the considerable contribution that Vanuatu's natural capital stock delivers to human society, locally, nationally and globally each year, which to a large extent falls outside formal traded markets and is not captured in national accounts.

- Subsistence gardens generate US$ 1.5 billion of value each year for Vanuatu; around double that of national GDP.
- Tanna is potentially significantly more heavily reliant than Vanuatu on ecosystem services for food (45%, compared to 16%) and provisioning services generally (81% compared to 70%).
- Subsistence gardens are important to the people of Tanna than for Vanuatu, contributing 44% of ecosystem service value, compared to 15%.
- Coral reefs present a greater proportion of ecosystem service value nationally than for Tanna (53%, compared to 39%).

These figures demonstrate the preponderance of attachment of very high economic value to provisioning ecosystem services for the people of Vanuatu (~70% of all ecosystem service value; approximately UD$ 7 billions per year, more than 10 times the GDP; ~81% for Tanna). Whilst regulating, habitat and cultural services undoubtedly contribute essential ecosystem services, the demand for food, raw materials, and water is direct, immediate and well-understood in the community. This has implications for data capture methods in future research into economic valuation of ecosystem services in least developed communities and perhaps suggests that discursive elicitation techniques should be used in parallel to traditional contingent valuation and choice experiments, to better capture social and shared benefits provided by the different ecosystem service types (Jacobs, et al., 2016; Kenter, Hyde, Christie, & Fazey, 2011).

The inclusion of subsistence gardens and plantation cropping as 'ecosystem types' begs the question of the trade-offs in land-use in support of food and raw material production; in particular the key trade-off between tropical forests and subsistence gardens. Ostensibly, at a per hectare per year level, the contribution of subsistence gardens and plantation crops (heavily modified, or transformed habitats) to food and raw materials is US$ 9,790; tropical forest contribute US$ 72 per hectare per year. At a TESV level, subsistence gardens and plantation cropping contribute \$10,274 $ha^{-1}yr^{-1}$, compared to tropical forests: \$2,739 $ha^{-1}yr^{-1}$. This

[6] In Kubiszewski, et al.'s (2017) paper, the scenario labelled 'Great Transition' is described as one where the SDGs are "largely met" (2017, p.293)

suggests net[7] conversion of tropical forest to subsistence gardens is economically rational and would form the basis of good policy in support of food security.

On Tanna, external pressures, such as climate change impacts and increased demand for food from population growth, will undoubtedly result in growing pressures on ecosystems, increasing the likelihood of degradation in their condition, and invoking transformational changes. Conversion of tropical forest to subsistence gardens is occurring at a significant rate on Tanna (Mackey, et al., 2017a; Mackey, et al., 2017b). At that same time, the island's population has increased from 29,731 to 32,934, with most census areas experiencing an increase (Mackey, et al., 2017a). Despite the increase in the area of cultivated land, there has been a reduction in the cultivated area per person. These trends suggest that increasing demand for food is resulting in the over-use of current agricultural land, leading to encroachment on forests in the search for more fertile soil for subsistence gardening. While tropical forests provide important ecosystem services, the benefits from the subsistence farming system meets that most basic and daily-pressing of human needs: food supply. Reported reductions in agricultural yields, most likely from root crop diseases and falling soil fertility from insufficient fallow periods[8], coupled with population growth that increases the demand for food, will likely lead to further deforestation pressures. This trend has implications for the ongoing protection of tropical forests on Tanna and their associated ecosystem services (particularly regulatory services), on which the subsistence gardens are dependent on. Experience elsewhere highlights that the risks of reductions in future yields may not become evident before thresholds have already been breached and state change becomes inevitable and thus the current ecosystem service condition is not necessarily the final equilibrium outcome of present drivers. It is unclear therefore if current fishing effort, for example, is within thresholds—the "safe operating space for coral reefs" (Hughes, et al., 546).

7.2. Limitations and caveats

Our mapping and benefit transfer approach enables a first pass valuation of the contribution of ecosystem services to the Vanuatu and Tanna economy and the resilience of local communities. However, a number of limitations to both the biophysical and economic aspects of the study are recognised and point to where useful additional research can be targeted:

(a) Our study lacks the information needed to be able to match the condition of Vanuatu and Tanna ecosystems with either the potential or realized flow of benefits. It is not contentious to assert the quality and quantity of the flow in ecosystem service benefits will decline with ecosystem condition. For example, while Tanna's coral reef ecosystems were judged to be in a consistent and good condition, there is a wide range in the condition of the island's tropical forests, which range from young secondary re-growth to old growth, primary forest. Site-specific survey data are needed in order for these relationships to be quantified and appropriate adjustments made to the monetary value of those ecosystem services, or in application of ecosystem disservices (Shackleton, et al., 2016) data to assess how encroachment of subsistence gardens on tropical forest can impact (particularly regulating) ecosystem services provided by the gardens.

(b) We did not attempt to derive a monetised valuation of one the most important benefits of tropical forest ecosystems in the Vanuatu context, namely, their kastom,

[7] Note: traditional subsistence gardening involves rotation cropping, see Section 2, whereby subsistence gardens and secondary regrowth tropical rainforest ecosystem types regularly interchange.

[8] This information is captured from informal conversations with government representatives on Tanna, whilst on field trips to the island (Mackey, et al., 2017).

or traditional customary use. The kastom use of forests is largely of a non-extractive nature, including cultural practices and harvesting of some non-timber based products. The cloud forest on Tanna, in particular, has both high biodiversity and kastom values. While it is not essential to obtain monetised valuations for every category of ecosystem service, it is worth investigating whether there are feasible approaches to valuing these to gain a more comprehensive set of ecosystem accounts, particularly as these forests are under pressure from poorly-regulated timber getting.

(c) Finally, our approach is based on valuations are based on a per unit area basis (hectares), which ignores that there are significant ecosystem characteristics and services that are scale- and/or linkage-dependent. Such characteristics include the capacity of a large area of tropical forest to regulate micro-climatic conditions, providing a buffer against droughts and fire. However, we lack the information to identify threshold values in the area of tropical forests below which specific services begin to degrade or disappear.

More broadly, the study identified there is a lack of ecosystem service valuation data based on studies and surveys conducted within Vanuatu (and Tanna) context, therefore it is uncertain whether the identified ecosystem service benefits are applicable and whether or not their potential benefit is realised in practice by the local community. The gaps in applicable data highlight anomalies; for example, Tables 8 is missing some important values for 'genetic resources' provided potentially by sea grass, mangroves, wetlands and grasslands and 'biological control' is highly likely missing an important value for tropical forests.

Moreover, most valuation methods generate estimates by assuming that social welfare (or the total value of a good, or the net social benefit of a project) is the sum of individual willingness to pay values. There is growing recognition that benefits associated with the environment are frequently inter-dependent (i.e., 'complex'); researchers who aggregate partial estimates to gain a TESV risk both double-counting 'overlapping values' (Hein et al., 2006) or precluding the possibility that inter-dependent values may be synergistic—that the whole may comprise more than the sum of its parts. The simple aggregation of individual estimates of 'value' may be inappropriate in some contexts; particularly when values are held at the community level (Adamowicz et al., 1998), therefore suggesting 'integrated valuation' or 'participatory valuation' elicitation methods will be more fruitful and useful (Costanza, et al., 2017, p. 8).

8. Conclusion

Notwithstanding the caveats and limitations, using GIS coupled with broad spectrum ecosystem services valuations has proved useful in providing rapid, remotely operable and cost-effective ecosystem service baseline information for policy-makers, even in relatively economic data-poor conditions. Such an approach can provide defensible data on which to make policy and programme assessments and to evaluate the often-hidden contributions of community interaction with ecosystems in sustaining well-being, particularly through the provision of food and raw materials. This approach can reduce barriers to enable policy makers in least developed countries to commission or undertake ecosystem service valuation – more pertinent as their populations are likely more reliant on ecosystem services.

Without revealing and demonstrating the value of ecosystem services, much of contributing factors to human and community well-being would remain unaccounted for. Critique of GDP as a proxy measure for human well-being is now well-developed in academia, amongst the development sector and is also now being adopted by national and state governments (Costanza, et al., 2017; Giannetti, Agostinho, Almeida, & Huisingh, 2015). However, progress in developing, codifying and publicising alternatives is slow (as outputs tend not to support political imperatives) and GDP remains a pervasive measure. Demonstrably, in Vanuatu, determining states and changes in individual and community well-being by measures of GDP is potentially out by a factor of 12. Such assessments can help inform alternative indices for community well-being, such as those explored in Alternative Indicators of Well-being for Melanesia (Malvatumauri National Council of Chiefs, 2012).

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