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ORIGINAL PAPER

Potential impact of invasive alien species on ecosystem services provided by a tropical forested ecosystem: a case study from Montserrat

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Abstract Local stakeholders at the important but vulnerable Centre Hills on Montserrat consider that the continued presence of feral livestock (particularly goats and pigs) may lead to widespread replacement of the reserve's native vegetation by invasive alien trees (Java plum and guava), and consequent negative impacts on native animal species. Since 2009, a hunting programme to control the feral livestock has been in operation. However long-term funding is not assured. Here, we estimate the effect of feral livestock control on ecosystem services provided by the forest to evaluate whether the biodiversity conservation rationale for continuation of the control programme is supported by an economic case. A new practical tool (Toolkit for Ecosystem Service Site-based Assessment) was employed to measure and compare ecosystem service provision between two states of the reserve (i.e. presence and absence of feral livestock control) to estimate the net consequences of the hunting programme on ecosystem services provided by the forest. Based on this we estimate that cessation of feral livestock management would substantially reduce the net benefits provided by the site, including a 46 % reduction in nature-based tourism (from $419,000 to $228,000) and 36 % reduction in harvested wild meat (from $205,000 to $132,000). The overall net benefit generated from annual ecosystem service flows associated with livestock control in the

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reserve, minus the management cost, was $214,000 per year. We conclude that continued feral livestock control is important for maintaining the current level of ecosystem services provided by the reserve.

Keywords Carbon · Feral livestock · Guava · Harvested wild goods · Java plum · Nature-based tourism · Non-native · TESSA

Introduction

Invasive alien species (IAS) pose serious threats to biodiversity, especially on islands (McGeoch et al. 2010; Peh 2010; Simberloff 2011). For example, IAS can dominate plant communities¸ especially after catastrophic disturbance events such as hurricanes and volcanic eruptions (e.g. Schmitz et al. 1997; Mack et al. 2000; Corlett 2010). Increasingly, there is also concern that IAS may impact ecological functions and processes, and hence the ecosystem services provided to people (Vitousek and Walker 1989; Pyšek et al. 2008). While impacts are variable, potentially even including enhancement of some services (Schlaepfer et al. 2011; Vila et al. 2011), there is clear potential for considerable detrimental impacts to services (e.g. de De Lange and van Wilgen 2010; Hickman et al. 2010). For example, functional changes in forest structure caused by invasive trees can alter above-ground and below-ground carbon pool sizes, and hence an ecosystem's capacity for carbon sequestration, while foraging and travelling patterns of invasive mammals can lead to habitat alteration by increasing soil erosion that can in turn lead to watershed degradation (Vtorov 1993; Nogueira-Filho et al. 2009). To date, there are many accounts of ecosystem services negatively affected by IAS (e.g. Martin et al. 2009; Asner et al. 2010; Pejchar and Mooney 2009) but only one study deals specifically with the consequences for ecosystem services of controlling IAS. De Lange and van Wilgen (2010) assessed the impacts of IAS management—using biological control—on ecosystem services. We add to this by explicitly assessing the effect of feral livestock control on ecosystem services provided by a forest reserve in Montserrat.

IAS are an environmental problem on Montserrat, a UK overseas territory (UKOT) of 10,200 ha located in the Lesser Antilles in the Caribbean (16°45′N 62°12′W). Montserrat has a moist tropical climate with natural climax vegetation distributed along altitudinal gradients, ranging from xerophytic scrub to evergreen rainforest and elfin woodland (Holliday 2009). However, a considerable proportion of these habitats has been converted or modified by human clearance for agriculture or development, and was altered by volcanic eruptions in 1995–1997. Much of the southern part of the island remains dominated by recent volcanic deposits (Fig. 1) and this formerly settled area is now designated as a formal 'exclusion zone' for humans, because of the risk of further eruptions. Due to net emigration since the volcanic eruptions, the human population of Montserrat now numbers about 5,000, a decrease from 10,200 people before the volcanic eruptions (United Nations Statistics Division, 2013). The area of Centre Hills (hereafter 'the reserve'; Fig. 1), currently gazetted under two designations—forest reserve (which belongs to the Crown) and protected forest (private land), is now the largest intact forest area remaining on Montserrat, and the last stronghold for the island's endemic flora and fauna (Allcorn et al. 2012).

After the destruction of the capital, Plymouth, and the disruption of the economy in the south, the human population now live in the northern, undeveloped half of the island near the reserve. The reserve is therefore under pressure from development to replace housing, business infrastructure and agricultural land lost as a result of volcanic activity. Moreover, the reserve harbours problematic invasive alien mammals—mainly feral pigs (*Sus scrofa*) and goats (*Capra hircus*)—whose populations have risen sharply since the volcanic eruptions because of the release of livestock by evacuated owners, along with recruitment to the feral populations from free-range livestock farms. The forest within the human exclusion zone on the south end of the island now represents a reservoir from which these mammals can disperse into the reserve.

Several ecological impacts of the feral livestock are being experienced on Montserrat (see Dawson et al. 2011). First, predation by invasive pigs threatens one of the last strongholds of the Critically Endangered (IUCN 2014) mountain chicken (*Leptpdactylus fallax*), a large frog whose population has already declined drastically due to infection by the chytrid fungus (García et al. 2009). Second, clearing of the understorey vegetation by foraging livestock indirectly affects the native bird species occupying the forest understorey. More specifically, consumption of the native lobster claw plant (*Heliconia caribaea*)

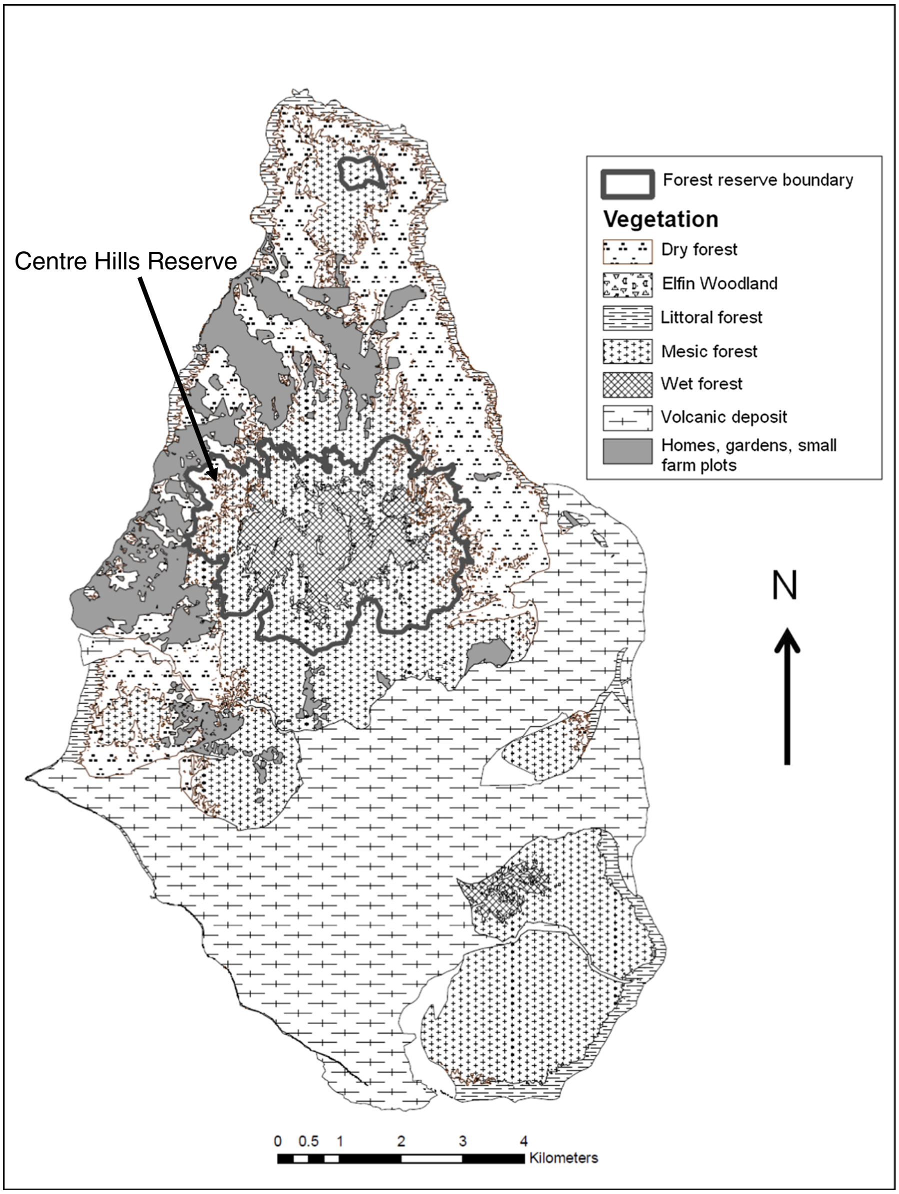

Fig. 1 Location of the Centre Hills forest reserve in the centre of the island of Montserrat. The exclusion zone is the whole of the southern part of the island, up to and adjacent to the reserve, and which is dominated by the recent volcanic deposits

causes the loss of nests of the Critically Endangered Montserrat oriole (*Icterus oberi*), a charismatic, endemic bird species which is one of the attractions for nature-based tourism on the island (Allcorn et al. 2012; Oppel et al. 2013).

Lastly, feral livestock activities reduce the abundance of native plant species (which evolved in their absence) and enhance conditions for the invasive alien plants Java plum (*Syzgium cumini*) and guava (*Psidium guajava*) (Nogueira-Filho et al. 2009). These fast-growing species (which require only a few years to mature and reproduce) have already formed dense canopies within the Centre Hills and at the periphery of the reserve (mainly in the volcanic exclusion zone), their establishment apparently aided over the last decade by feral livestock (pers. obs., James Daly). Pigs are the main seed dispersers of these plants (see Global Invasive Species Database, www.issg.org); hurricanes aid their establishment by creating gaps in the forests, and the goats further help by opening up the understorey of the native vegetation. The saplings of both invasive plant species are not eaten by the livestock, as their leaves have low palatability and digestibility (Smith 1991; Kibria et al. 1994). These species have already naturalised in some Pacific islands where they are considered as "dominant invaders" because they spread rapidly forming dense stands and causing severe impact on native plants (Meyer 2000).

Since July 2009, the Montserrat Department of Environment (DOE) has implemented an invasive animal management strategy. This involves permitted trapping and hunting with firearms (in both the reserve and nearby parts of the exclusion zone), educating livestock owners in the surrounding area about better animal management practices, and improving a livestock tagging and registration scheme. A preliminary assessment of these measures indicated that they are effective in reducing the feral livestock populations in the reserve (Dawson et al. 2011). However, the impact of this feral livestock management programme on the ecosystem services the reserve provides to people was unknown. For example, while the reduction of the feral livestock might help to maintain the endemic population of Monserrat Oriole, and thus sustain the nature-based tourism, it was not clear if it reduces the supply of wild meat. Furthermore, the future funding of this programme is not assured. Given the lack of knowledge on the wider socio-economic benefits of reducing feral livestock numbers, information about its net economic consequences would help to decide if the costly programme should be continued. Given evidence that the reserve generates substantial ecosystem services (van Beukering et al. 2008), we examined how cessation of feral livestock management might affect the delivery of the most important of these benefits. Specifically, we used a newly developed rapid assessment tool (TESSA—Toolkit for Ecosystem Service Site-based Assessment (Peh et al. 2013a); available at http://www.birdlife.org/datazone/info/estoolkit and described in Peh et al. 2013b) to estimate the net impact of livestock control on carbon storage, nature-based tourism and the provision of harvested wild meat derived from the reserve.

TESSA was chosen over other tools [e.g. Integrated Valuation of Ecosystem Services and Tradeoffs (InVest; Tallis et al. 2013), and Assessment and Research Infrastructure for Ecosystem Services (ARIES; Bagstad et al. 2011), etc.] because it enabled the personnel at DOE to collect high resolution site-scale data that is relevant to the decisions affecting the site without the need for specialist technical knowledge on modelling approaches and using GIS software, intensive field work or substantial investment of resources; these practical features are currently lacking in alternative methods (Peh et al. 2013b). Therefore, TESSA was the most appropriate tool to use in this relatively rapid and inexpensive study, by non-experts from a governmental department (Montserrat DOE).

Methods

Study area

The reserve, located in the central region of Montserrat (Fig. 1), is one of four hill ranges modified from six old volcanic cones (MacGregor 1938). The reserve covers 1,130 ha and rises to 741 m (van Beukering et al. 2008). The soils are primarily volcanic in origin, comprised mostly of clay and sandy loam (van Beukering et al. 2008). The area has a distinct wet season from July to December, and a dry season from February to May. The annual rainfall average in this region is 1,475–2,000 mm, with large annual and seasonal variations depending on the number and severity of tropical storms affecting the region (Barclay et al. 2006). Forest in the reserve was legally protected in 2000, with new environmental legislation currently pending. Two-thirds of the area is privately-owned and one-third is government-owned. A network of springs across the Centre Hills provides the island population with drinking water. The extraction and distribution of water are overseen by Montserrat Utilities Ltd.

The reserve is mostly forested, consisting of several vegetation types: (1) dry forest (102 ha); (2) mesic forest (635 ha); (3) wet forest (381 ha); and (4) elfin shrub-woodland (8 ha; Fig. 1). Dry forest occurs at the lowest elevation of the reserve, where precipitation is also comparatively low. The common plant species in this forest type are *Cedrela odorata*, *Chiococca alba*, *Guaiacum officinale* and *Hymenaea courbaril*. At higher elevation, dry forest is replaced by mesic forest, with a more developed understorey shrub layer, with species including *Begonia oblique*, *H. caribaea*, *Inga* *laurina* and the endemic shrub *Rondeletia buxifolia*. Wet forest occurs on steeper slopes above 500 m. Its characteristic flora includes palms, tree ferns and the trees *Asplundia insignis*, *Phyllanthus mimosoides* and *Podocarpus coriacetus*. On the highest peaks and ridges elfin woodland grows, comprising shrubby vegetation dominated by *Wercklea tulipiflora*. Besides the endemic globally threatened Montserrat Oriole and mountain chicken, the reserve also supports an extremely rare lizard called the Montserrat galliwasp (*Diploglossus montisserrati*). These unique animals that inhabit the reserve are the main attractants for the people visiting the island.

Assessing ecosystem services

We used the TESSA toolkit (Peh et al. 2013a, b) to compare ecosystem service provision between two states of the reserve. TESSA brings together a selection of accessible, low-cost methods to identify the important ecosystem services provided by a site, and to evaluate the magnitude and distribution of the benefits that people get from them now, compared with those expected under alternative land-uses.

The counterfactual, alternative state is a description of how the future (we assume the next 10–20 years) may plausibly develop. Comparing service provision between states is more useful to decision-makers than quantifying the gross benefits from the current state (Balmford et al. 2011), as it sheds light on the net consequences of decisions. Here we compare (1) the current state, in which feral livestock populations are reduced via active management, and (2) a plausible alternative state, identified through discussion with local stakeholders, in which feral livestock control is absent, leading to higher livestock densities and impacts on native flora and fauna.

As TESSA is designed for rapidly comparing service delivery between two states, it does not have the resolution to describe changes in service provision through time. Therefore we did not consider in detail the timeline of the feral livestock invasion without the feral control programme, nor discount rates into the future. However, the current feral livestock management team (including experts from the UK Animal Health & Veterinary Laboratory and The Royal Society for the Protection of Birds) and the forestry team from the Montserrat DOE expected that the lack of control would lead–over the next 10–15 years–to Java plum-dominated stands (which can thrive in wet conditions) replacing the mesic forest, wet forest, and elfin woodland, and guava-dominated stands (which can tolerate drier conditions) replace the dry forest (for habitat description of both invasive plant species, see: Global Invasive Species Database, http://www.issg.org/database; also see Meyer (2000) for specific case studies in the Pacific). Based on these expectations, the alternative state of the site we assessed involved the replacement of a combined area of 1,024 ha of mesic forest, wet forest and elfin woodland by Java plum-dominated forest, and the replacement of 102 ha of dry forest by guava-dominated forest. Based on field observations in this study, 83 ± 11 % (mean ± 95 % confidence intervals, based on 12 stands) of the stems in the forest invaded by Java plums belonged to the invasive species, while 96 % of the stems (based on one stand) in the forest invaded by Guava were the invasive species. Therefore these realistic estimates represented the level of dominance by these invasive species under the alternative state.

Working with stakeholders, we used TESSA's rapid appraisal protocol to identify all services provided by the site of interest. Users of the forest will recognise and value different services. The range of services identified was also guided by a previous economic assessment of the ecosystem services generated by the Centre Hills (van Beukering et al. 2008). A workshop of stakeholders in March 2011 then further assessed and identified those services that are (1) important in either biophysical, social or economic terms; (2) sensitive to feral livestock invasions; and (3) amenable to rapid quantification using TESSA. These were: global climate regulation (through carbon storage and greenhouse gas fluxes), nature-based tourism, provisioning of harvested wild meat from feral livestock and water provisioning. The ecosystem services identified by van Beukering et al. (2008) matched this suite of services, except that our list did not include the harvesting of mountain chicken, fruits and crayfish. This is because mountain chickens are now rare in Montserrat and the collection of fruits and crayfish in the reserve is now carried out infrequently, as a leisure activity, by a few individuals only.

By quantifying these services for both states, we estimated the overall annual value for each state, subtracted that of the current state from that of the alternative state, and hence derived an estimate for the net economic consequences of cessation of feral livestock control. All economic values in this study were converted from East Caribbean dollars (EC$) to US dollars using the 2011 average exchange rate (EC$2.70 = $1).

Global climate regulation

To estimate the storage of carbon (C) in above-ground biomass (AGB), we used a combination of field data collection (in June 2011) and reference to the Intergovernmental Panel on Climate Change (IPCC) tier 1 database (IPCC 2006). The reserve was first stratified by vegetation type: dry forest, mesic forest, wet forest, and elfin shrub-woodland. We estimated the C stock in the AGB of elfin shrub-woodland from Table 4.12 in the IPCC (2006) tier 1 database. In each of the three other vegetation types we randomly located six 5 m × 100 m transects, at least 200 m apart and accessed by narrow walking trails. Along each transect, we measured diameter at breast height, D (cm) of all trees ≥10 cm and estimated the height, H (cm) of all mature palms. Tree measurement followed standard protocols (Phillips et al. 2009) and AGB (Mg) was estimated using the following regression models derived from Brown (1997):

$$AGB_{wet} = 21.297 - 6.953 \times D + 0.740 \times D^2 \quad (1)$$

$$AGB_{mesic} = \exp(-2.289 + 2.649 \times \ln D - 0.021 \times \ln D^2) \quad (2)$$

$$AGB_{dry} = 0.2035 \times D^{2.3196} \quad (3)$$

The AGB of palms was estimated as in Delaney and Roshetko (1999):

$$AGB_{palm} = 4.5 + 7.7 \times H \quad (4)$$

The above equations are widely accepted and commonly used in the literature (e.g. Pearson et al. 2005). The amount of above-ground C stored in trees and palms was assumed to be 50 % of the AGB (Chave et al. 2005). We determined the sample size requirements for each forest type based on the pilot results, in order to attain a precision level of ±10 %. As a result in total we measured 13 transects in the wet forest, 14 transects in the mesic forest and 8 in dry forest. As the reserve is legally protected, we assumed there was no loss of C stocks due to human disturbance such as wood harvesting. Although the reserve is subject to occasional hurricane-force winds, we did not take into account the C loss due to storm damage because we assumed that direct effects of strong winds on the tree-covered reserve were minimal (see van Bloem et al. 2006; Imbert and Portecop 2008).

To estimate carbon storage under the alternative stage we measured diameter at breast height of all trees ≥10 cm within all the accessible Java plum stands and all trees of the only guava stand on the island (most of the stands of these exotic species are in the volcanic exclusion zone, and therefore not accessible). We estimated their carbon storage capacity using the following regression model (Delaney and Roshetko 1999):

$$AGB_{invasive} = \exp(-2.134 + 2.53 \times \ln D) \quad (5)$$

In all, we measured 12 monodominant Java plum stands of a total of 0.30 ha and one guava stand of 0.11 ha.

Below-ground biomass carbon stock was estimated using a below-ground biomass: AGB ratios for particular vegetation types (IPCC 2006). Estimates of litter and dead wood C stocks were drawn from Anderson-Teixeira and Delucia (2011). Estimates of mineral soil C were derived from the IPCC (2006) tier 1 database. The total carbon stock of each state was then the summation for each habitat type of all the following components: above-ground C, below-ground C, litter C, dead wood C and mineral soil C.

Greenhouse gas (which consisted of carbon dioxide, methane and nitrous oxide) sequestration rates of the tree species in the two alternative states of the forest were determined by reference to Anderson-Teixeira and Delucia (2011). However, this provides no information on variation was provided between different species in these tropical forest communities, so we assumed the greenhouse gas sequestration rate in the two states to be constant.

Nature-based tourism

The opportunity to view rare endemic species such as Montserrat oriole and to walk in the cloud-shrouded tropical forest attracts international tourists to the reserve. The annual value of this nature-based tourism was estimated from an international visitor questionnaire survey at the airport, conducted in April and May 2011 (for the interview questions see Appendix 1) and the 2009 records of tourist numbers from the Montserrat Tourism Board (which has the record for 1 year only). The airport is the main gateway to the island for international visitors. Based on variance in expenditure reported in the first ten interviews, we used power analysis to calculate that the minimum sample size needed to estimate expenditure to a precision level of ±20 % was 52 interviews. The tourism revenue from a tourist to the reserve was estimated as the mean expenditure per day spent on a trip to the island—including the costs of air travel to Montserrat, accommodation, car rental and meals—multiplied by the number of days spent at the reserve. The annual expenditure on visiting the reserve was derived by multiplying the mean expenditure per day per tourist by the total number of tourists to the island in 2009. In the questionnaire, for the tourists who had visited the reserve, we asked if they would come to the reserve if the area remained forested but its unique biodiversity had disappeared (see Appendix 1). The likelihood of all unique species becoming extinct is high under the alternative state because they are classified as either endangered (e.g. Montserrat Oriole) or critically endangered (mountain chicken) due to their limited distributions and small populations, and the known threats from IAS. To establish an estimate of the value of tourism under the alternative state, the percentage of tourists who would visit the alternative state was multiplied by the estimated current annual expenditure on visiting the reserve. As the approach used was a simplified version of the Travel-Cost Method (TCM), we did not collect enough information on characteristics (e.g. income) of interviewed people to run a full TCM analysis. Despite having relatively robust estimates of tourist expenditures, i.e. costs (for travel, accommodation, food, etc.) incurred by each tourist in travelling to the reserve for recreational purposes, we acknowledge that this approach is an incomplete measure of the economic value of nature-based tourism because our estimate was less than the maximum amount that the tourists may have been prepared to pay (Wells 1997).

Harvested wild meats

Hunting feral animals provides an important supply of meat for the island. We looked at two sources—private hunting, and official DOE hunts. We gathered anonymous data from four hunters (27 % of the total hunting population; 3 DOE, 1 non-DOE) on the quantity of meat (broken down by species) which they privately collected from the reserve (i.e. excluding the meat collected during the official hunting trips for the Department) in the 6 months to June 2011, on the proportion they sold, and on the capital costs of their hunting activities. To deduce the value of harvested feral meat for the alternative state, we asked the DOE hunters to estimate the amount of meat they would have collected in the past 6 months if they had received no income for DOE hunting and were prevented from accessing the exclusion zone (as they had been before the DOE began feral animal control; for the questionnaire see Appendix 2). We assumed that the hunting effort of the non-DOE hunters would be the same under the two states.

Data on the number of animals shot and amount of meat collected from the reserve and the exclusion zone during official DOE hunting trips was obtained from records of 27 May 2010 to 16 February 2011. Meat acquired during the official DOE trips was not sold for profit, but was provided to the community (e.g. to nursing homes and prison facilities). This benefit would only be obtained under the control programme and not in the alternative state, and we assumed that its value was equal to that of the meat which was sold.

Water provisioning

Montserrat's water supply is sourced from nine springs, situated across the Centre Hills reserve, which feed immediately into pipes and a network of 18 tank reservoirs. About 55 million litres of water were extracted and used by the island population per month from 2001 to 2006 (van Beukering et al. 2008). The reserve forest is important for the protection of the watershed and associated erosion risks. However, increases in feral mammal numbers are not likely to impact this water provisioning service because the springs and reservoirs are fenced off and protected by concrete structures to prevent water contamination. It is possible that the eventual change in tree species composition, with replacement of native species by alien species, will affect hydrological parameters such as the amount of rainfall intercepted, evapotranspiration rates and through fall kinetic energy, and hence erosion risk (e.g. Geissler et al. 2013). However, measurement of such parameters was beyond the scope of this study and it is not possible to state in which direction effects might be observed. In light of this we conservatively assume that feral animal control had no net benefit for water provisioning by the reserve.

Results

Global climate regulation

We estimated the mean above-ground C stock in the reserve to be 106.3 ± 16.4 (95 % confidence interval) Mg C ha^{-1} for wet forest, 186.1 ± 32.6 Mg C ha^{-1} for mesic forest, 40.4 ± 14.5 Mg C ha^{-1} for dry forest, 134.9 ± 43.5 Mg C ha^{-1} for Java plum stands and 18.8 ± 5.0 Mg C ha^{-1} for guava stands. The total carbon stock (across the five pools of carbon) of the reserve was estimated to be 341,000 Mg under the current state, whereas that under the alternative state was 302,000 Mg (Table 1). Hence the carbon stock loss that is avoided under the current state was calculated to be 39,000 Mg (Table 1). At a carbon price of $83.61 per tonne (US Government; Greenspan Bell and Callan 2011), this benefit of avoided carbon loss was estimated at $3,240,000. However, we acknowledge that our estimates of carbon stocks for the current and alternative states were subject to wide nominal errors (Table 1); this highlights the importance of using local field data wherever possible in such assessments as the uncertainty derives mainly from using IPCC values. Although carbon stock might decline with no control of IAS, the broad estimate ranges do not indicate the significance of the change (Table 1). Therefore we conservatively assume there was no benefit of avoided carbon loss under the current state.

Given the resolution of available data, we assume no change in carbon sequestration rates following the spread of invasive plants. Increases in abundance of ungulates (i.e. goats, sheep and cattle) in the reserve will lead to increased methane emissions but, without an assessment of absolute livestock numbers in the reserve, we are not able to quantify the potential change in methane emissions that might occur if feral animal control ceased.

Nature-based tourism

We interviewed a total of 95 international visitors at the airport departure hall. Based on this survey, 37.2 % of the international tourists on Montserrat had visited the reserve during their stay. We estimated their mean expenditure on visiting the reserve to be $178.35 ± 43.09 per person. There were a total number of 6,311 visitors on Montserrat in 2009. Therefore, we estimated that 2,350 international tourists visited the reserve in 2009, and their total annual expenditure on their visits was $419,000. Only 54.3 % of the respondents indicated that they would visit the reserve under the alternative state; this would therefore generate a total annual expenditure of $228,000. Therefore our estimate of the decrease in value associated with the loss of native fauna at the reserve was $192,000 per year (Table 2).

Harvested wild meat

We found that 15 hunters harvest feral livestock from the reserve on a regular basis and sell meat from these private trips into the island market. Five of these hunters were also members of the DOE hunting team, for which they received a salary. Unfortunately, we were not able to interview all hunters about their level of activity, because their income was regarded as a sensitive topic. The sample size of the hunter survey was therefore only four, but it constituted over a quarter of the hunter population on the island. Information obtained from the sole non-DOE hunter in the sample was assumed to be representative of the other nine non-DOE hunters. The market prices obtained for the beef, pork, mutton and goat were US$4.50, $7.30, $6.10 and $6.10 per kg, respectively. The assessment of the total annual net profit from feral animal hunting took account of the sale price of the meat harvested, and capital costs (e.g. tools, maintenance of hunting dogs and meat cutting fees) (Table 3). Under the feral livestock management scheme, the total annual profit from both private and official hunting trips—was calculated to be $205,000. Under the alternative state, without the DOE hunting programme, the total annual profit was estimated to be 36 % lower, totalling $132,000 (Table 2).

Feral livestock management costs

The current management programme entails reduction of feral livestock populations in and around the reserve, monitoring the populations using a network of infra-red game cameras and implementing a tagging and registration scheme for non-feral livestock. The

Table 1 Estimates of carbon stored in live AGB (tree ≥10 cm diameter in breast height), below-ground biomass, litter, dead wood and soil of various habitat types in the current state (A; feral livestock control) and the most plausible alternative state (B; no feral livestock control) of the Centre Hills reserve

Habitat type	Area (ha)	Above-ground C		Below-ground C		Litter C		Dead wood C		Soil C		Total*
		(Mg/ha)	Mg	CF	Mg	(Mg/ha)	Mg	(Mg/ha)	Mg	(Mg/ha)	Mg	
A. Control												
Wet forest	381	106.3	40,500.3	0.37	14,985.1	10	3,810	20	7,620	130	49,530	116,445 (53,021–179,870)
Mesic forest	635	186.1	118,173.5	0.24	28,361.6	10	6,350	20	12,700	70	44,450	210,035 (127,216–292,854)
Dry forest	102	40.4	4,120.8	0.28	1,153.8	10	1,020	20	2,040	50	5,100	13,435 (4,198–22,672)
Elfin woodland	8	35.0	280.0	0.40	112.0	6	48	0	0	80	640	1,080 (422–1,738)
Total	1,126**		163,074.6		44,612.5		11,228		22,360		99,720	340,995 (184,856–497,134)
B. No control												
Java plum forest	1,024	134.9	138,137.6	0.20	27,627.5	10	10,240	20	20,480	Varies	94,620	291,105 (140,757–488,420)
Guava forest	102	18.8	1,917.6	0.56	1,073.9	10	1,020	20	2,040	50	5,100	11,151 (2,744–18,830)
Total	1,126		140,055.2		28,701.4		11,260		22,520		99,720	302,257 (143,502–507,250)

The above-ground carbon storage in living biomass for wet forest, mesic forest, dry forest, Java plum stand and guava stand were measured using data collected on site. The estimates of carbon stocks in the AGB of elfin woodland and soil were drawn from the IPCC (2006) tier 1 database. The estimates of below-ground biomass carbon stocks for all habitats were calculated using habitat-specific below-ground biomass to AGB ratios (CF) (IPCC 2006). The estimates of carbon stock for litter and dead wood were taken from Anderson-Teixeira and Delucia (2011)

* Totals figures are rounded to nearest integer and are mean and, in parentheses, the potential range (maximum–minimum). Errors vary between carbon stocks. For soil, the IPCC guidelines suggest a nominal error of ±90 %. No errors are given for litter or dead wood, so we assume 90 %. As stated in the methods, above-ground carbon (and hence below ground carbon) is calculated to a precision of 10 %

** Of the total reserve area of 1130 ha, 4 ha are small water bodies

Table 2 Net values of all services (for which economic values were available) resulting from continuation of Montserrat's invasive alien mammal control programme

	Control	No control	Difference
Service (flow) (\$ year^{-1})			
Nature-based tourism	419,049	227,509	191,540
Harvested wild meat	204,834	131,844	72,990
Feral livestock management cost	−50,410		−50,410
Net annual benefit	573,473	359,353	214,120
Net annual benefit per hectare	507	318	189

programme was funded by a UK Overseas Territories Environment Programme (OTEP) fund of \$101,000 (based on a mean 2011 exchange rate of £0.6235:US\$1) for 2 years, starting in March 2011. Since early 2013, it has been continued through a further grant from the European Commission 'BEST' fund. The cost of feral livestock management was therefore estimated at \$50,500 per year; this covers wages for hunters, allowances for dogs, transport, hunting equipment, project management, financial assistance to owners for better livestock practices, staff training and DOE overheads.

Net economic consequences of continuation of feral livestock management

The overall net benefit generated from annual ecosystem service flows (nature-based tourism and harvested feral livestock) associated with livestock control in the reserve, minus the management cost, was \$214,000 per year (Table 2). According to our estimates, cessation of feral livestock control would reduce benefits to both local people (through harvested wild meat) and global beneficiaries (via nature-based tourism and carbon storage) (Table 4). The cessation of feral livestock control would likely cause the decline or disappearance of native species in the reserve. Consequently, global stakeholders such as the foreign investors who own the restaurants and hotels on the island, as well as the locals who hold jobs in service and supply industries, would suffer from reduced incomes from tourism. Local communities would lose out through a reduced supply of wild meat.

Discussion

Many studies have estimated values of ecosystem services at a national or regional level (e.g. Pimentel et al. 2000; Zavaleta 2000) but fewer have performed this kind of assessment at a local scale to yield results to inform local decision-making. As far as we know, this is the first ecosystem service assessment addressing a decision concerning IAS control. We found that cessation of the feral livestock management in Montserrat could reduce the net benefits provided to people by the Centre Hills Reserve, including a potential 11 % reduction in carbon storage, 46 % reduction in tourism (due to the loss of native species) and 36 % reduction in large mammal hunting. In total, unmanaged feral livestock could cause a loss of service flows of \$265,000 per year—a value that is about 5 times the cost of feral livestock management. This study thus suggests that evaluating ecosystem services can provide novel and important information to help guide decisions about feral livestock management.

This study extends and updates a previous evaluation of the economic value of the reserve (van Beukering et al. 2008) in several ways. Firstly, the previous study used IPCC look-up table data to calculate that 621 Mg of carbon could be lost per year, assuming an annual loss of 2.8 ha (0.25 %) of the forest. Our results suggest the potential for invasive animals to have a further impact on carbon stock by changing the tree community, even without forest loss. This impact has also been seen with the highly invasive tree *Morella faya*, in Hawaii, which decreased AGB in woodland-savanna ecosystems (Asner et al. 2010). Secondly, the previous study estimated that 32 % of people's motivation for visiting Montserrat could be attributed to activities related to the reserve bringing US\$7.5-9.3 million per year (c. 25 % GDP) since 2000 (van Beukering et al. 2008). We estimated that the total value of tourism at the reserve was \$419,000 per year, dropping by 46 % to \$228,000 if the anticipated ecosystem changes occurred.

Finally, van Beukering et al. (2008) estimated the value of harvested wild goods (including timber, crayfish and even the endemic mountain chicken frog) at \$158,000 per year, with a large proportion (81 %) derived from pig hunting (based on information from two hunters). We found that the feral livestock management programme, which has influenced the

Table 3 (a) The estimated total value (US$ per year) under the current state (feral livestock control) and the most plausible alternative state (no feral livestock control), assuming meat collected during the official DOE trips would have received the market price

	Control		No control			
	Official DOE hunting trip		Private hunting trip in CH			
	CH	EZ	DOE	Non-DOE	DOE	Non-DOE
(a)						
Pig	0	1,279	4,218	26,640	41,958	26,640
Goat	12,619	28,950	1,390	0	4,170	0
Sheep	427	2,075	463	0	1,390	0
Cattle	0	79,432	4,216	65,280	6,936	65,280
Total	13,046	111,736	10,287	91,920	54,454	91,920

Capital Cost (US$/year)	Control	No control
(b)		
Cutting fee	18,366	10,741
Dog	750	750
Dog maintenance	2,639	2,639
Machete	400	400
Total	22,155	14,530

	CH	EZ	Total	Total minus capital costs
(c)				
Control	115,253	111,736	226,989	204,834
No control	146,374	0	146,374	131,844

The prices of the wild meat are: pig, US$3.33/Ib; goat: US$2.78/Ib; sheep: US$2.78/Ib; and cattle: US$2.04/Ib. (b) Capital costs associated with hunting of 15 hunters. (c) Summary CH = DOE hunter in Centre Hills, EZ = DOE hunter in exclusion zone. DOE = DOE hunter on private trip, Non-DOE = non-DOE hunter on private trip. Cutting fee based on a charge of US$ 0.19 lb/year

private hunting behaviour of hunters, has led to an increase in the total value of wild harvested mammal meat to an estimated total of $205,000, largely by allowing access to the exclusion zone. Without the feral animal control programme, and assuming continued lack of private access to the exclusion zone, the value of wild harvested meat would reduce by over a third.

Determining the most suitable approach for dealing with the feral livestock (e.g. control vs. eradication) is not simple (Myers et al. 2000). The current control program in Montserrat is aiming at area-specific suppression of the feral livestock population, as eradication is not possible due to inaccessibility of most of the exclusion zone. Interestingly, our results also imply that the current feral livestock control approach may be more economically beneficial than eradication as it yields meat worth $205,000/year for local consumption. However, our analysis of benefits from hunting feral meat did not involve any consideration of the population dynamics of the feral livestock. Although hunting drastically reduces feral livestock activity in and around the reserve, it has little impact on the feral livestock population as the exclusion zone—harbouring most of the feral livestock—occupies a considerable area and is largely inaccessible. In the absence of the control programme, however, it is unlikely that the total off-take of meat could remain the same or increase because there are limitations among the Montserrat population in terms of technical capacity (e.g. use of traditional hunting methods is less efficient than use of firearms during IAS control), physical capacity (the work is arduous and hence generally unattractive) and local knowledge of the physical environment required for successful hunting in Montserrat's hilly terrain.

To reflect differences in the uncertainty associated with our estimates for each services, we used a simple scale of 'high', 'medium' and 'low' to assess the degree of confidence, as recommended by TESSA (Table 4). Based on these standards, our confidence is 'low' for our estimates of carbon stocks between the two alternative states. This is because our estimations using imperfect allometric relationships and published look-up tables have wide nominal errors. We therefore did not include the net carbon stock benefit in the

Table 4 Magnitude of change in delivery of different services in the alternative state (cessation of invasive alien mammal control), shown for beneficiaries at the local (Montserratian only), national (includes new immigrants from nearby islands) and global scale (includes foreign investors who owned the restaurants and hotels on the island)

Ecosystem service	Location of beneficiaries			Level of confidence
	Local	National	Global	
Change in annual flows				
Greenhouse gas sequestration	=	=	=	Medium
Nature-based tourism	=	=	↓↓	Medium
Harvested wild meat	↓	=	=	Low
Water provision	=	=	=	Low
Change in stock				
Carbon storage	=	=	↓	Low

"↓" indicates decrease, "=" indicates no change and number of symbols indicates relative magnitude of change. Categories of level of confidence are based on the classification scheme provided in Peh et al. (2013a)

estimate of the net values of all services resulting from continuation of IAS control programme (Table 2). Nevertheless, it is worth mentioning that a critical component of valuing carbon stock is the choice of carbon prices. These prices—adjusted to a 2011 baseline using the International Monetary Fund's inflation rates (http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/weorept.aspx)—range from $22.75 per tonne C (Verified Emission Reductions; Peters-Stanley et al. 2011), to $56.18 per tonne C (EU's Emission Trading Scheme; Point Carbon 2011), $118.09 per tonne C (Tol 2010), $319.33 per tonne C (UK Government; Greenspan Bell and Callan 2011) and $348.13 per tonne C (Stern et al. 2006). Hence, the net carbon stock benefit is highly sensitive to a chosen carbon price.

The distribution of economic impacts is a further complicating factor. For instance, the livestock management programme is counted as a "cost" of $50,500/year, which includes wages, financial assistance to livestock owners, and other expenses which are indeed a cost to taxpayers or funding agencies, but are actually a benefit to island residents and others employed by the programme. It is debatable therefore whether, say, hunters' wages should be counted on the red side of the ledger while revenue from the sale of livestock meat is counted on the black. Likewise, the economic benefits from the tourism industry would likely not accrue to the same individuals or institutions who would incur the costs associated with livestock control.

Admittedly, a full life cycle of cost-and-benefit analysis, which is beyond the scope of this assessment, is needed for the most informed decisions. We also did not consider time horizons and discount rates since this study–in contrast with alternative methods based on modelled scenarios of projections into the future–was a comparison between two different states of the reserve as 'snapshots' in time for which real data were collected. We therefore recognise that we did not consider the long-term change in delivery of services. Nevertheless, a simple assessment of benefits based on realistic estimates derived from the reserve enabled us to draw some useful and highly relevant conclusions for the decision context of this case study. Stakeholders at the reserve now have an idea how the net benefit from the feral livestock control programme compares with the costs of such a programme.

This study suggests that the feral livestock management programme in Montserrat should continue for economic, as well as conservation reasons. Indeed, the community of Montserrat recognise the threat of invasive species to the biodiversity and services of the reserve and, on average, is willing to pay $58 per household per year (in 2008 US$) for the control of invasive species (van Beukering et al. 2008). However, feral livestock management programmes are often inadequately funded (Campbell and Long 2009). Despite the recognition of its importance by the population of Montserrat and international conservationists, the Centre Hills management scheme is currently funded only until 2015. Continued financing is essential to help protect this reserve. The economic case for its continuation suggests that it may be timely to develop an ecosystem service-based scheme to underpin the financial requirements of long term conservation of the reserve, using combinations of private and public financing mechanisms that have been explored, for instance, for reserves in Costa Rica (Bernard et al. 2009).

In assessing who might pay for feral livestock control, it is important to consider how the benefits might be captured. For some services this will prove difficult. For instance, the relatively small size of the potential carbon stock change in the forest reserve and the complexity of the monitoring methods that would need to be developed might make it a relatively unattractive prospect for the formal carbon market, although possibilities might exist to engage in the voluntary carbon offsetting market. Tourism will continue to be important for the Montserrat economy, but new mechanisms will be required to ensure that the resulting benefits from nature tourism are equitably distributed among those who play a role in keeping these services available, whether local communities, civil society organisations, business or government. Some form of modest tourism or green visitor exit tax might offer the best opportunity for sustainable finance. Lessons learned from schemes in other Caribbean UK Overseas Territories indicate that a very robust mechanism for distribution of green tax revenue needs to be in place from the outset of any proposed scheme.

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Appendix 1: interview questions for tourists at the department hall of the airport on Montserrat

Interview date:

Number of people in the travel group:

1. Have you visited the Centre Hills during your stay in Montserrat?
   Yes—Please complete the rest of the questionnaire.
   No—End of the survey.
2. How many days will you spend away from home whilst on this trip?
   N.B. This should also include the days you spend elsewhere outside Montserrat, for example other Caribbean islands, if there are any.
   Answer: ________________
3. In total, how much money will you spend during your whole stay in this trip?
   (per person, or for the whole group)
   N.B. A) This should include your spend on travel (air, ferry, etc.), accommodation, food, local transport, tour guide, etc.
   B) This should include your spend elsewhere outside Montserrat, for example other Caribbean islands, if there are any.
   Answer: ________________ (per person/for the whole group*)
   * delete where appropriate
4. How many days have you spent at the Centre Hills during your trip?
   Answer: ________________
5. Would you come to the Centre Hills for these activities if the Central Hills remain forested, but the unique animals of Montserrat (e.g., Montserrat Oriole) have disappeared?
   Answer: Yes/No*
   * delete where appropriate.

Appendix 2: interview questions for hunters on Montserrat

Interview date:

1. How much meat (in terms of lbs)—for your own use and sale - did you collect from the Centre Hills in the past six months?
   (NB. Do not include the meat collected from DOE hunting trips)
   Answer: ______
2. What percentage of the meat is from pig, goat, sheep and cattle?
   Pig _____ %
   Goat _____ %
   Sheep _____ %
   Cattle _____ %
3. Would your answer to Q1 change if there is no additional income from DOE hunting trips? If yes, what is the estimated amount of meat you would have collected for the past six months? **
   Answer: ______

** Question for the Department of Environment hunters only.

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