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Integrating conservation, restoration and land-use planning in islands—An illustrative case study in Réunion Island (Western Indian Ocean)

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A B S T R A C T

This paper describes an operational protocol for integrating conservation and restoration with land-use planning in islands. Conservation challenges are intensified in insular systems due to higher ecosystem vulnerability, limited spatial options, low data availability, rapid land-use change and, globally, short-term vision planning. Our operational planning protocol integrates ecological and socio-economic factors to identify the best spatial options for conserving and restoring biodiversity, inside and outside extant reserves, while minimising future land-use conflicts. Conservation and restoration targets are formulated for species, habitats and ecological processes that support biodiversity. An optimal network of priority sites is selected to achieve those targets across the landscape. The prioritisation process integrates a Conservation Costs Index to optimise conservation and restoration investments. We discuss the outcomes of the planning protocol in terms of site prioritisation, stakeholders' participation and general implications for spatial planning in insular systems. As with many islands, the study area of Réunion Island has experienced rapid urban and agricultural expansion, which threatens its unique biodiversity. Forty three per cent of the island is currently protected in a National Park but only half of this reserve network contributes to the achievement of targets. An additional 21% of land should be conserved mainly to ensure the persistence of ecological connections between the marine, terrestrial and freshwater realms. Finally we emphasize that our method doesn't substitute the land-use planning debate but is aimed to better prepare the conservation sector for negotiating future land-use allocation with other socio-economic sectors in islands.

1. Introduction

Spatial planning in islands must carefully balance ecosystem persistence requirements with insular development. Over the last century, insular ecosystems have become some of the most restricted and threatened in the world (Mueller-Dombois and Loope, 1990). For instance, more than 60% of documented vertebrate extinctions have occurred on islands (Diamond, 1989; Case et al., 1992). Islands ecosystems are particularly rich in endemic species, and contribute disproportionately to global biodiversity (Stattersfield and Capper, 2000). Conservation and restoration in islands is a major challenge since 10 of the 34 terrestrial biodiversity hotspots listed by Conservation International are wholly comprised of islands (Mittermeier et al., 2005; Cook et al., 2006). To address this challenge, we developed and tested a spatial planning protocol to optimise conservation and restoration investments in the landscape while minimising potential conflicts with other land-uses in islands.Confounding ecological and anthropogenic factors

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have been cited to explain unprecedented rate of biodiversity loss in islands. This includes the rarity of spatial options for biodiversity persistence (Simberloff, 1995; Whittaker et al., 2001), a higher vulnerability of ecosystems to invasions (Mueller-Dombois and Loope, 1990; Fritts and Rodda, 1998), and higher rates of land conversion (Cudihhy and Stone, 1990). Poor spatial planning in insular ecosystems has led to disastrous, rapid and irreversible biodiversity loss (Dolisca et al., 2007). In addition, several factors hinder the implementation of conservation actions in insular regions, i.e. poverty, poor knowledge and data, and, overall, insufficiently integrated conservation strategies.

Conservation plans initiated in insular regions often focused on biodiversity only and ignored socio-economic factors that guide effective conservation (Veech, 2003). This often resulted in unsustainable conservation strategies due to conflicts between islanders' interests and conservation (Novy-Hildesley, 2001). For instance, such conflicts hindered conservation implementation in the Galapagos (Grenier, 2000) and in New-Zealand (Young, 2004). Although islands share common social and ecological traits with continental areas, many conservation challenges are intensified in insular systems.

Following systematic conservation planning principles (Balmford, 2003; Margules and Pressey, 2000), our protocol aims to identify *ex ante* the best spatial options for conserving and restoring a representative sample of biodiversity features and ecosystem processes inside and outside an extant reserves network, while minimising conflicts with other land uses. After presenting conservation challenges in Réunion Island (Section 2), we describe the planning protocol (Section 3): mapping habitats, species and biodiversity processes (Section 4), setting conservation and restoration targets (Section 5), identifying priority sites for conservation and restoration (Section 6). Outcomes of the plans are analysed in Section 7. Finally, we propose implementation mechanisms toward a better integration of conservation and restoration issues within land-use planning in Réunion Island (Section 8), and more generally in insular regions (Section 9).

2. Conservation and land-use planning challenges in Réunion Island

Réunion Island (2512 km^2) is a small French island located in the Indian Ocean, 200 km South-West of Mauritius and 700 km to the East of Madagascar (Fig. 1). Its steep volcanic relief reaches 3070 m in the centre of the island. A third of its areas is still covered by native vegetation ranging from lowland rainforest to subalpine grassland (Strasberg et al., 2005).

The island has long been recognised as a global priority for conservation owing to its high concentration of endemic taxa, especially of plants. Forty six per cent of the 843 species of vascular plants species in Réunion Island are endemic to the Mascarene region that is comprised of Mauritius and Rodrigues Island (Cadet, 1980; Conservatoire Botanique National de Mascarin, 2008). Réunion Island is comprised in a terrestrial and a marine biodiversity hotspot (Roberts et al., 2002; Mittermeier et al., 2005).

At present, more than 80% of the 802,000 inhabitants (INSEE, 2009) live on the coastal fringe where most of the socio-economic activities are concentrated. Population has been increasing at rate of 1.5% per year since 2000 and is predicted to reach 1 million inhabitants in 2030 (INSEE, 2009). European Development Funds boosted the economy of the island since the 1990's. Concomitantly, urban areas expanded by 189% over the period from 1989 to 2002 (Durieux et al., 2008) and available land became a rare and coveted resource. Below 1000 m, landscapes are now expected to fulfil multiple functions (i.e. urbanisation, agriculture production and ecosystem conservation) and this causes conflicts among stakeholders about their planning and management (van der Valk, 2002).

Since the European occupation of the island (in 1665), lowland habitats (<1000 m) are almost fully transformed, except on harsh slopes and ravines (Gigord et al., 1999) (Fig. 1). As with other insular regions, biodiversity in Réunion is facing escalating threats that have already led to the extinction of 30 of 45 vertebrate species (Mourer-Chauvire et al., 1999). Habitat degradation by invasive alien species is an important threat to its endemic biodiversity (MacDonald et al., 1991; Baret et al., 2006). Ecosystem conversions by urbanisation and agriculture (mainly sugar cane and market gardening) are destroying remnant pristine vegetation patches in the lowlands, while forestry and native forest clearing for cattle breeding are major threats to biodiversity in the uplands (Strasberg et al., 2005). Since the creation of a National Park in 2007, 43% of the area of the island is protected (Table 1). However, the reserve network is biased toward the uplands: the mean altitude of reserves is 1306 m versus 873 m for the whole island. With very few protected areas in the lowlands, the persistence of biodiversity in Réunion Island depends heavily on the successful integration of conservation and restoration strategies with land-use planning.

Future challenges for land-use planning in Réunion Island further include the control of urban sprawl and the protection of agricultural land from conversion by urbanisation. A *regional development plan* ("Schémad'AménagementRégional": hereafter referred to as SAR) rules the allocation of land uses for the whole island. The SAR developed in 1995 was under revision at the time of this analysis. Therefore, our objective was to produce conservation and restoration recommendations that could inform the SAR revision process. In addition there was a demand from the National Park authorities to identify priority areas for conservation and restoration inside the National Park boundaries.

3. Planning protocol overview

Our conservation and restoration planning protocol is based on systematic conservation planning principles (Margules and Pressey, 2000). As a first step, the conservation and land-use challenges were assessed and the institutional demand for spatial planning was identified during preparatory meetings with stakeholders from the urban, agriculture and conservation sector and scientists (Section 2). As a second step, we gathered spatial data on biodiversity for three different types of biodiversity features, i.e. (1) pristine habitats, (2) endemic species and (3) spatial components of ecological and evolutionary processes (Section 4). Conservation and restoration targets were formulated for those features (Section 5). After assessing the level of target achievement in existing conservation areas (i.e. a "gap analysis"), we identified additional priority areas to meet targets while minimising costs associated with conservation implementation, management, restoration and current and future land-use trends (Section 6). This was done using a site selection algorithm embedded in MARXAN software (Ball and Possingham, 2000). The site selection process follows eight stages (Table 3) that achieve incremental conservation and restoration targets into a spatial network of priority sites (see Section 7). Finally, we identified implementation mechanisms to better integrate conservation and restoration opportunities with land-use planning, inside and outside the existing reserve system (Section 8.4). The results of the site selection process plus the implementation recommendations constitute what we refer to as the "conservation and restoration plan".

The plan was developed through a participatory process. An advisory team of 10 professionals, constituted mainly of scientists (i.e., geographer, anthropologist, agronomist, modeller and ecologist), but also staff of the National Park authorities were

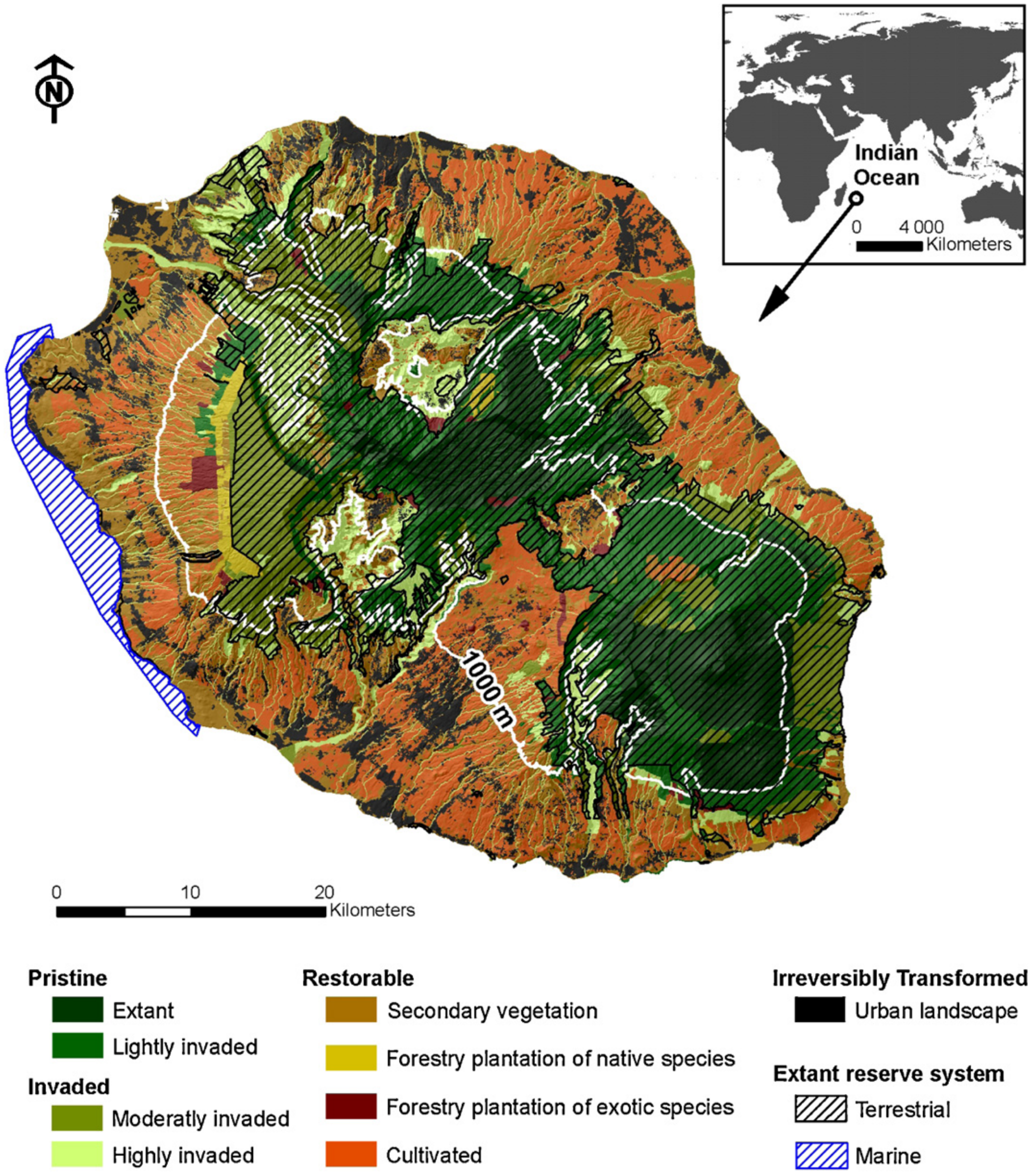

Fig. 1. Habitat transformation and reserves distribution in Réunion Island (from Strasberg et al., 2005).

Table 1
Protected areas categories in Réunion Island (terrestrial only). Spatial overlaps occur between protected areas.

IUCN category type	Protected areas category	Area (km^2)	(% of island's area)
Type I	Biological forest reserve	278	11.0
Type II	Core area of the National Park (including cultivated and inhabited areas)	1048	41.7
Type IV	Nature reserve	38	1.5
	Biotope reserve	20	0.8
	Biological reserve of the National Forest Office	76	3.0
	Sites of the Conservatoire du Littoral (coastal conservation agency)	8	0.3
Total		1071	42.6

consulted during workshops and individual interviews. Institutions involved in the land-use planning debate on the island were informed of the on-going conservation planning process throughout regular meetings and presentations. The strategy for the participation of stakeholders is specifically discussed in Lagabrielle et al. (2010): they concluded that the participatory development of land-use simulation models should be promoted to explore alternative scenarios for biodiversity conservation with stakeholders. They also showed that this participatory planning approach should be gradual and sequential to fit into public decision-making processes.

4. Mapping biodiversity

4.1. Habitats

In areas where available data on biodiversity are poor or limited, a coarse-filter approach to mapping biodiversity is recommended

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(Margules and Pressey, 2000). To this purpose, habitats act as good surrogates for overall biodiversity (Lombard et al., 2003).

To develop the habitat map in Réunion Island we integrated expert judgements with remote sensing data and GIS analysis. Pristine habitats were extracted from Strasberg et al. (2005). These were modeled using slope, altitude and rainfall data combined with aerial photography analysis (Strasberg et al., 2005).

As we aimed to develop a habitat map compatible with conventional land-use products, we combined GIS data on urbanisation and agriculture by collaborating with institutions involved in the land-use planning debate. The GIS layer on urban areas was provided by the Regional Urban Planning Agency (AGORAH). GIS layers on agriculture (cane, other crops and pastures) were validated by the Regional Agriculture Council (ChambreRégionaled'Agriculture). We integrated those GIS datasets following a set of rules defined with the participants, with urban areas superimposing all other features.

We mapped a system of 44 habitat classes, including 21 pristine classes (Fig. 1). Habitat classes, their current and past extent, are detailed in Appendix A. Each habitat class – including urban and agricultural areas – was attributed a transformation status by conservation experts (Table 2). The transformation status categories were derived from Strasberg et al. (2005) and Baret et al. (2006): *extant* (i.e. pristine), *invaded* (pristine remnants but alien species covering more than 50% of the under storey and more than 90% of the canopy), *restorable* (secondary vegetation and agricultural areas) and *irreversibly transformed* (urban areas).

4.2. Species

Due to time and budgetary limitations, we only used existing species datasets. We concentrated our data collection effort on threatened species. Unsurprisingly, these were distributed almost exclusively in lowlands where habitat transformation is the most prominent in Réunion Island. The combination of distributional data on threatened species with data on pristine habitats in reserve selection is an efficient and satisfactory approach to overall biodiversity representation (Payet et al., 2010). Payet et al. (2010) developed their study in Réunion Island using the dataset developed for this conservation and restoration plan.

We collected GIS layers on 25 indigenous species, including eight endemic plants, the breeding areas of five oceanic bird species and the distribution areas of nine endemic forest birds, two reptiles and one bat species (Appendix B). The threat status of species was assigned according to the IUCN Red List of Threatened Species (IUCN, 2006). The species data are representative of conservation priorities in the lowlands, although biased toward iconic bird and reptile species.

4.3. Ecological and evolutionary processes

Biodiversity in insular regions is sustained and generated by a wide array of ecological processes (such as movements of endemic species) and evolutionary processes (such as speciation processes along altitudinal gradients) (Whittaker et al., 2001). Identifying, mapping and protecting areas supporting such processes are important to guarantee the persistence and long-term evolution of ecosystems. This can be achieved by complementing the network of protected areas by large-scale corridors that represent key ecological linkages between marine, freshwater and terrestrial realms. Corridors are aimed to capture the environmental gradients and maintain landscape connectivity across spatial and temporal scale (Rouget et al., 2006). They facilitate biota movement and maintain evolutionary processes such as geographic speciation (Moritz, 2002).

We used the recently developed map of *Spatial Components of Biodiversity Processes* (SCBPs) developed by Lagabrielle et al. (2009) in Réunion Island. SCBPs are landscape features supporting key biodiversity processes, such a bird migration, plant dispersal and geographic speciation, along environmental gradients or ecological interfaces (Rouget et al., 2006). Lagabrielle et al. (2009) proposed a method to identify those biodiversity processes and delineate a network of conservation corridors maximising their protection while minimising current and future threats.

SCBPs were mapped as surface elements aligned along linear environmental interfaces or gradients. These comprised oceanic–terrestrial interfaces, riverine corridors, macrohabitat interfaces, topographic unit boundaries, and lowland–upland gradients. The mapping method involved consultation of experts, GIS analysis and an extensive literature review. The transformation status of SCBPs ranked from *extant* in pristine habitats, through *restorable* in crop or secondary vegetation, to *irreversibly transformed* in urban areas.

A regional network of 23 large-scale natural corridors linking sea-level areas to the island summits were designed to encompass a maximum amount of SCBPs and pristine habitats while avoiding areas incompatibles with the maintenance of ecological connectivity (Lagabrielle et al., 2009).

5. Formulating conservation and restoration targets

Formulating conservation and restoration targets for biodiversity features is a necessary step toward prioritizing actions (Desmet and Cowling, 2004). A conservation (or restoration) target is a quantitative estimate of the minimum portion of each biodiversity feature that needs to be represented in the conservation (or restoration) protected area network to ensure their long-term persistence (Pressey et al., 2003).

Targets for habitats were expressed as a percentage of their individual original area, i.e. before human transformation. Targets were calculated on original rather than current extents because habitats are typically unequally affected by anthropogenic impacts (Desmet and Cowling, 2004). Targets were then formulated into hectares required per habitat type.

Habitat targets were obtained by summing a *baseline target* of 20% and an *adjustment target* comprised between 0% and 30%. This composite approach, mixing a fixed and a variable target, is advocated by Rondini and Chiozza (2010). The *baseline target* of 20% is in line with international conservation agreements (Convention on Biological Diversity). The *adjustment target* is driven by local data on the ecological heterogeneity and natural rarity of habitats types. For each habitat type, the *adjustment target* was calculated as the sum of the following variables (with values scaled from 0 to 10): species richness, endemic species richness and environmental heterogeneity. Species richness data were extracted from a previous study by Strasberg et al. (2005). The calculation of the environmental heterogeneity was based on the following parameters: soil type diversity (data from Raunet, 1991) and coefficient of variation of altitude, slope and precipitation. Final habitat targets (*baseline* + *adjustment target*) in Réunion rank from 24% to 45%. Given their uniqueness in the region, the entire current extent of untransformed wetlands and lava flows habitats was targeted (Fig. 2). When the conservation target exceeded the pristine extent of a given habitat, the conservation target was truncated to that extent and the remaining area became the *restoration target*. Only six pristine habitats ended with a restoration target: five lowland habitats almost fully transformed by urbanisation or agriculture and the *subalpine Sophora thicket* habitat recently transformed by cattle farming in the uplands.

Conservation targets for species were defined as a fraction of distributional area or number of distributional sites. Targets were

Table 2
Categories of habitat transformation in Réunion Island.

Transformation status	Description	Reference	Area (as % of total)*
Pristine			
Extant			*26.9*
Pristine	Not invaded or presence of some alien plant individuals in an intact canopy and understorey (alien species <1%)	Strasberg et al. (2005) Baret et al. (2006)	7.7
Lightly invaded	Canopy intact (native species cover >90%) but understorey invaded (10–90%)	Strasberg et al. (2005) Baret et al. (2006)	19.3
Invaded			*25.3*
Moderately invaded	Canopy and understorey invaded (Native species cover between 50% and 90% in the canopy)	Strasberg et al. (2005) Baret et al. (2006)	12.8
Highly invaded	Canopy and understorey invaded (Native species cover between 10% and 50% in the canopy)	Strasberg et al. (2005) Baret et al. (2006)	12.5
Transformed			
Restorable			36.3
Secondary vegetation	No native species	Lagabrielle et al. (2009)	17.7
Cultivated	Crops including forestry	Lagabrielle et al. (2009)	18.6
Irreversibly transformed	Urban areas	Urban Planning Agency of Réunion Island (AGORAH)	*9.9*

* The transformation status of 1.6% of the island's areas remains unknown.

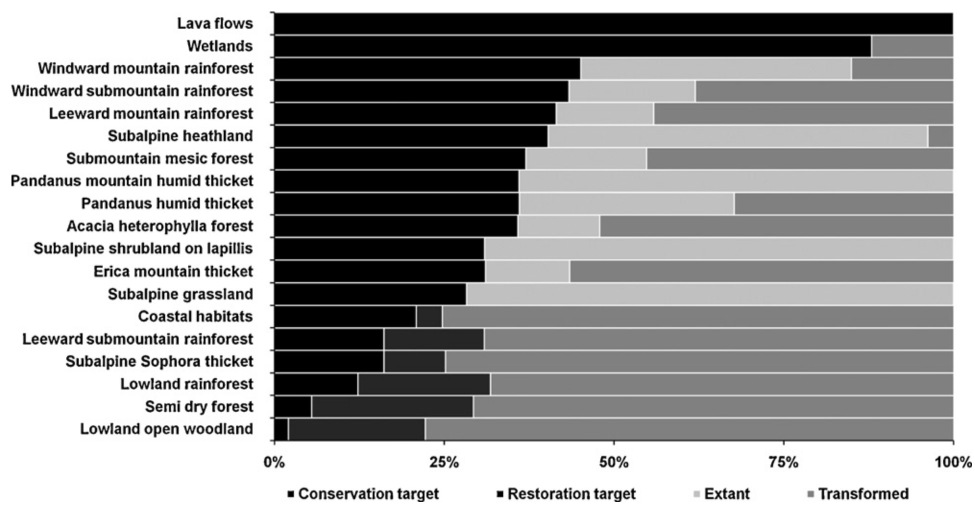

Fig. 2. Conservation and restoration targets for pristine habitat in Réunion Island, expressed as a percentage of the total area of each habitat.

set according to species status in the IUCN Red List of Threatened Species (IUCN, 2006): 100% for species seriously on the verge of extinction (number of species = 7) or threatened with extinction (*n* = 4), 80% for vulnerable (*n* = 2), 60% for near threatened (*n* = 1) and 40% for least concern species (*n* = 11, including two species protected by ministerial decree). Given the low availability of data on species, those targets were arbitrary decided with conservation experts.

All extant and restorable sections of SCBPs and corridors were attributed a 100% conservation or restoration target given. Those spatial features are required to maintain functional ecosystems on the island (Lagabrielle et al., 2009).

6. Identifying spatial priorities for conservation and restoration

6.1. Site selection process

The site selection process is aimed at identifying priority sites for conservation and restoration, inside and outside the extant reserve system. This protocol integrates previous systematic conservation planning procedures proposed by Cowling et al. (2003) and Rouget et al. (2006), appended with a systematic restoration planning procedure. A spatial algorithm is used to optimise the site selection process. The eight stages of the site selection process are described in Table 3.

6.2. Conservation and restoration costs

As conservation resources are limited, conservation and restoration costs need to be assessed and optimally allocated (Naidoo and Ricketts, 2006). To assess those costs, we developed a Conservation (and restoration) Costs Index (CCI). The CCI is calculated by summing the following cost components: *conservation implementation cost* (the cost of implementing additional reserves), *conservation management cost* (the cost of managing protected areas), *restoration management cost* (the cost of managing habitat restoration, in addition to conservation management cost) and *transformation pressure cost* (the cost of trying to prevent future probable habitat transformation or destruction by land conversion or invasive species). The CCI variables are detailed in Table 4. CCI variables and overall values were linearly rescaled from 0 to 100 to facilitate cost analysis, data combination and integration into MARXAN software.

To calculate the *transformation pressure cost*, the outcomes of three predictive models were combined, i.e. on urbanisation, agricultural and plant invasion potentials. Urbanisation probabilities were derived from non-linear regression analysis on 12 factors explaining urban sprawl observed from 1989 to 2002 (Thinon

Table 3
Stages of the site prioritisation process for conservation and restoration planning. The irreplaceability value is the frequency of site selection along successive runs of MARXAN.

Stage	Objective
Conservation	
1	Integrating extant SCBPs[a] outside reserves
2	Integrating sites of high irreplaceability (>0.8) to achieve conservation targets for habitats, plants and vertebrates inside existing reserves
3	Integrating sites of high irreplaceability (>0.8) to achieve conservation targets for habitats, plants and vertebrates outside existing reserves
4	Integrating lowland–upland corridors outside existing reserves
Restoration	
5	Integrating restorable sections of SCBPs outside existing reserves
6	Integrating restorable sites of high irreplaceability (>0.8) to achieve restoration targets for habitats inside existing reserves
7	Integrating restorable sites of high irreplaceability (>0.8) to achieve restoration targets for habitats outside exiting reserves
8	Integrating restorable sites selected in stages 2, 3 and 4

[a] SCBPs = spatial components of biodiversity processes. This includes oceanic–terrestrial interfaces, riverine corridors, macrohabitat interfaces, topographic unit boundaries, and lowland–upland gradients.

Table 4
Components of the Conservation Costs Index (CCI). Values range between 0 and 100.

Cost component	Rationale
Implementation	Reserve implementation costs depend on land's ownership: public land is cheaper than private land. We considered that land price were homogeneous in private land
Conservation management	Conservation management costs are the investments required to manage protected areas. In insular regions the control of alien plants is a major conservation management cost (Baret et al., 2006). This cost is minimum in pristine habitats and maximum in invaded habitats. Other management costs were assumed homogeneous across the landscape: control of poaching activities, maintenance of hiking trails, etc.
Restoration management	Once conserved and managed, the restoration of existing transformed ecosystems involves massive investments. Restoration cost increases with the level of transformation of ecosystems. This cost is null in pristine habitats and maximum in irreversibly transformed habitats
Transformation pressure	The transformation pressure is the probability of future ecosystem transformation by urbanisation, agriculture and invasive plants. Dealing with a high transformation probability requires investments (communication, fencing, negotiation and juridical fees among others) to resist to the transformation pressure. The occurrence probability vary from 'not probable' (score = 0) to 'highly probable' (100)

et al., 2007) and calibrated using population projection for 2030. Suitability map for agriculture (sugar cane and pastures, which are the dominant agricultural activities in Réunion Island) were provided by the Chambre Régionale d'Agriculture de La Réunion. Future potential extents of invasive plants were mapped by Baret et al. (2006) using Climatic Envelope Modelling. We summed the potential extent of the 20 most invasive species for this analysis. The transformation pressure probabilities vary from 'not probable' (score = 0) to 'highly probable' (100). We derived the mean score among the three equally weighted factors (urbanisation, agriculture and alien plants) as the final *transformation pressure cost*. The mean score method was preferred to the highest-score method owing to the high intensity and density of transformation pressures across the planning domain (saturation effect).

6.3. Identifying optimal sites for conservation and restoration

To select sites that optimally achieve conservation and restoration targets in the landscape we used the conservation planning software MARXAN (Ball and Possingham, 2000), and its interface CLUZ (Smith, 2004) in Arcview 3.2 (ESRI, Redlands, California).

MARXAN software is designed with the use of stochastic optimisation routines (simulated annealing, Kirkpatrick et al., 1983). The algorithm attempts to identify a near-optimal reserve system, called *solution*, which best achieves conservation targets while minimising a set of costs (Possingham et al., 2000). Planning units frequently integrated within *solutions* are the most *irreplaceable* (MARXAN sensu).

In our case study, the optimisation process aimed to minimize the following three variables when selecting the additional reserve network:

- The "fine" (also called *Species Penalty Factor* in MARXAN) to be paid if a conservation or restoration target wasn't achieved. We heuristically attributed to this parameter a prohibitive penalty value of 10 million per absent or under-represented biodiversity feature. Thus we ensured that each solution adequately represented all biodiversity features targeted in the plan.
- Second, the average value of the Conservation Costs Index (CCI) within each planning unit. Thus, we ensured that low-cost planning units were preferred to high-cost planning units.
- Third, the Boundary Length Modifier (BLM) which is the overall cost associated with reserve boundaries. Increasing the BLM promotes the compactness of the reserve network identified. The BLM is the sum of all reserve boundaries costs across the planning region. In the model, boundaries costs can be weighted according to the type of reserve boundaries. For instance a boundary with a dense urban areas (less preferable) should inherits a higher weighting factors than a boundary with secondary vegetation (more preferable). In practice, BLM and CCI are highly correlated (i.e. a high surface cost is associated with a high boundary cost). For this reason, and in order to avoid double accounting, boundaries costs weights were set as constant all over the planning region. Thus, the BLM was used as an independant control knob to adjust the overall compacteness of the reserve network, without considering the type of reserve boundaries.

For the purpose of the analysis, the planning domain was divided into hexagonal cells of 10 ha. Hexagonal cells are equidistant and have six adjacent cells when square cells only have four. The hexagonal net was then intersected with the boundaries of the extant statutory reserves, SCBPs and municipalities. The resulting layer is the best compromise between data processing constraints, spatial resolution of input data and compatibility with current land-use planning maps.

7. Results

7.1. Priority sites

Extant reserves cover 43% of the area of the island (Fig. 3). Only 50% of the area of this extant reserve system contributes to

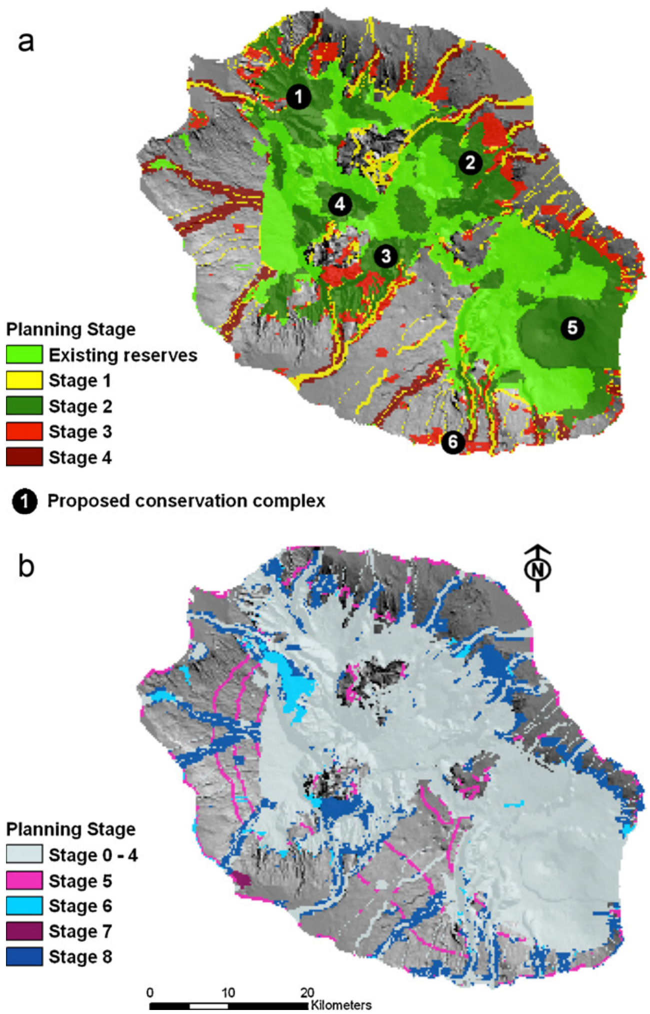

Fig. 3. Priority areas selected along a) the conservation stages (i.e. stages 1–4) and b) restoration stages (5–8). Six priority conservation complexes were identified, namely 1) the Leeward dry complex, 2) windward humid complex, 3) submountain and mountain complex, 4) subalpine complex, 5) active volcano complex, and 6) coastal complex.

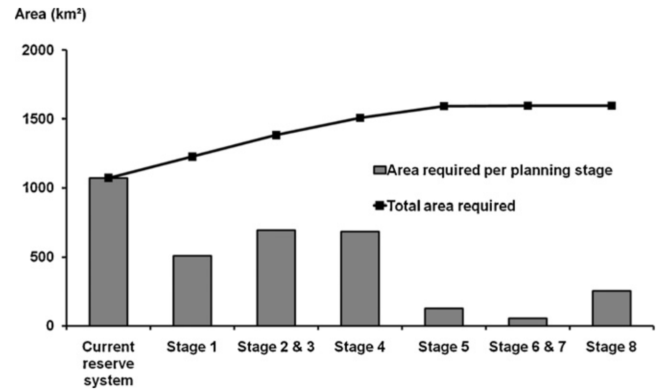

Fig. 4. Area required at each stage of the conservation and restoration plan. The curve of the total area required reaches a plateau at stage 5 since restoration targets could be achieved within zones selected in previous stages.

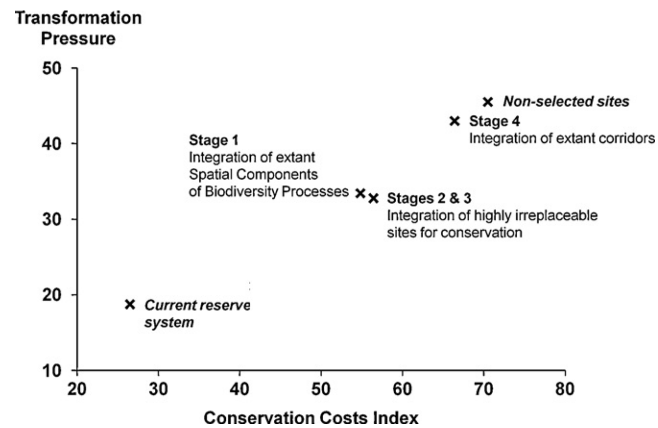

Fig. 5. Mean *transformation pressure* and *conservation costs index* in additional areas selected along the stages of the conservation plan. Values range between 0 and 100.

achieve conservation and restoration targets (i.e. 50% of the extant reserve doesn't contribute to achieve targets). This means that half of the area of the National Park is redundant in terms of target achievement. To achieve all targets, in addition to the extant reserve system, 21% of the island should be protected for conservation or restoration purpose.

The conservation plan requires the protection of an additional 437 km^2 of land (17% of the island). This consists mainly of areas represented in the corridors linking the lowlands to the uplands and on the external margin of the National Park. Based on this analysis, we identified six large conservation complexes that could guide conservation implementation. Those biodiversity complexes comprise priority areas for conservation identified inside and outside the current reserve system (Fig. 3a). The restoration plan requires only an additional 88 km^2 of land (4% of the island), mainly for coastal habitats restoration.

7.2. Target achievement

All conservation and restoration targets are predicted to be achieved through the integrated conservation and restoration plan. Within the extant reserves system, 14 habitats (out of 21) and 9 vertebrates (out of 17) had their conservation targets achieved but all plants species ($n = 8$) are still under-represented (Table 5). Indeed, these are plants that are distributed in the lowlands, outside the extant reserves system. For some features, over-achievement was substantial. For instance, five habitats had their targets achieved by more than 200%. Almost all restoration targets could be achieved within sites already selected for the conservation plan (Table 5). Indeed, very few additional sites were selected in the restoration plan (Fig. 4).

7.3. Costs

The mean value of the Conservation Costs Index (CCI) is 26 inside the extant reserve system against 65 outside (Fig. 5). Highest costs (maximum = 93) are found in the lowlands where habitat transformation by urbanisation, agriculture and invasive plants is highly probable. In additional sites selected for the conservation and restoration plan, the mean CCI value is 63 whereas this value is 70 in non-selected sites.

The mean CCI value increases in additional areas selected along the planning stages of the conservation plan. Indeed to achieve conservation targets, the site selection is forced to integrate costly sites in the lowlands (high-cost, high pressure). For instance, in stage 1 (SCBPs conservation) the mean CCI value is 54 against 66 in stage 4 (corridors conservation) (Fig. 5). The *transformation pressure* (i.e. probability of ecosystem transformation) follows the same pattern: low in the extant reserve system (=19) and globally high in non-protected areas located in the lowlands (=41) where conflicts between conservation/restoration interests and other land uses are more likely to occur. Finally, owing to its lower CCI val-

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Table 5
Number of biodiversity features per category of target achievement (in %): in the current reserve system and incrementally from the conservation through to the restoration plan.

Target achievement category (%)	Number of features		
	Current reserve system	Conservation plan	Restoration plan
Habitats (conservation plan)			
<100	6	0	0
≥100 < 200	9	15	15
≥200 < 300	2	2	2
≥300	3	3	3
Habitats (restoration plan)			
<100	4	1	0
≥100 < 500	2	5	5
≥500 < 1000	0	0	0
≥1000	0	0	1
Vertebrates (conservation plan)			
<100	8	0	0
≥100 < 150	1	9	9
≥150 < 200	7	0	0
≥200	1	8	8
Plants (conservation plan)			
<100	8	0	0
=100	0	8	8

ues, the South-West coast of the island has a great potential for restoration.

8. Discussion

8.1. Overview of the planning protocol

Our planning protocol allows the integration of conservation and restoration planning requirements within a single framework. It also considers the current and future costs associated with the implementation and management of conservation/restoration activities inside and outside reserves. The conservation and restoration plan integrates 64% of the island, including the existing reserve system. As a point of comparison, the conservation plan designed for the Cape Floristic Region by Cowling et al. (2003) incorporated 49% of lands.

Despite covering 43% of the island, the current reserve system (mainly represented by the National Park) has a limited contribution to biodiversity targets. However, the current conservation network needs to be expanded toward the lowlands to conserve a viable sample of all habitats and species. Due to rapid changes in land-use trends, we stress that lowland–upland corridors should be implemented urgently to ensure the persistence of ecological and evolutionary processes along altitudinal gradients. As with many islands, building this network (Jongman, 1995) linking the marine, terrestrial and freshwater realms (Beger et al., 2010) is vital for the persistence of biodiversity in Réunion Island. This lack of protection in the lowlands and this "over-protection" in the uplands highlights the need for proper conservation planning in insular systems.

8.2. Conservation and restoration costs

The analysis of conservation costs in Reunion Island reveals that the National Park was implemented in the "cheap uplands" whereas the expansion of protected areas and the implementation of future corridors cannot avoid high-cost areas to achieve conservation targets.

We developed a Conservation Costs Index (CCI) that incorporates current and future costs associated with conservation and restoration activities. A similar approach integrating ecological and socio-economic factors for restoration planning was also recently proposed by Orsi and Geneletti (2010). The integration of costs into the planning process allows the optimisation of conservation and restoration investments in the landscape. The CCI is based on weights attributed to four cost components. Theoretically, modifying those weights could change the outcomes of the plan. Nevertheless, in practice, given the rarity of spatial options in Réunion Island, the main drivers of the site selection process remain the conservation and restoration targets. Indeed, the main contribution of the CCI is to arbitrate locally between sites that are equivalent in terms of their contribution to the achievement of targets.

To complement this approach, a cost–benefit analysis of conservation activities should be undertaken to balance costs with broader socio-economic benefits arising from ecosystem conservation/restoration. To this purpose, an assessment of ecosystem services would be useful to compare conservation against other spatial planning options such as agriculture or urbanisation. The costs and benefits of different land-use scenarios could then be tested.

8.3. Data limitations

The plan rests on limited data on biodiversity features and an incomplete understanding of ecosystem requirements. A major portion of biodiversity patterns and processes still remain cryptic (Gaston and Spicer, 2003). We used distribution data and locality records for a small subset of rare plant and vertebrate species but we did not integrate data on invertebrates which is the largest single component of biodiversity (Redak, 2000). We assumed that habitats act as good environmental surrogates for species but we didn't assess quantitatively this relationship. Furthermore, we delineated habitat units at broad scale (1:50,000) but finer scale habitats were not explicitly targeted in the plan. In addition, our plan doesn't take into account the intra-taxa diversity (Moritz, 2002).

Our conservation targets are based upon a very rough estimate of biodiversity persistence requirements in Réunion Island. Ideally, conservation targets for habitats should be derived from species-area curves and species turn-over but such data are generally not available (Desmet and Cowling, 2004). Targets set for species were based upon their status in the World Red List of Endangered Species. This list is still incomplete, biased toward emblematic species, and status updates are sporadically initiated in small islands.

8.4. Implementation strategies

Three complementary management and implementation strategies should be undertaken in Réunion Island: (1) focusing management interventions inside the National Park on priority areas identified in the plan, (2) expanding the existing reserve system in large low-cost areas located on the margin of the National Park, and (3) focusing investment on a subset of high-cost areas supporting key biodiversity features and processes in the lowlands. To this purpose, an efficient solution would be to focus investments on conservation corridors linking the terrestrial National Park to the marine realm and more particularly the Marine Reserve (Fig. 1). The implementation of the first strategy depends on the National Park authorities but the two others depend directly on the willingness of stakeholders to protect biodiversity outside extant reserves. We propose some implementation mechanisms below.

Expanding the boundaries of the National Park seems currently unrealistic. Rather we suggest integrating conservation measures within the management plan of the Voluntary Stewardship Zone ("Zone de LibreAdhésion") that surrounds the National Park. Municipalities are the members of this zone, which is ruled by a common management charter. Membership is renegotiated every 10 years. In return, municipalities must develop and implement sustainable land-use plans, compatible with biodiversity conservation.

The implementation of corridors will require the integration of heterogeneous land management regimes from the seashore to the summits (Lagabrielle et al., 2009). The implementation of corridor management measures across the landscape should be based on land care and stewardship programmes through financial incentives and training initiatives dedicated to private owners. Such corridors could provide linkages between the Terrestrial National Park and the Marine Natural Reserve on the west coast (Fig. 1). We suggest the implementation of "Inter-realms Corridors" and the creation of "Inter-realms Corridors Management Committees" to mainstream corridors conservation within land management and planning (Beger et al., 2010; Lagabrielle et al., 2009).

8.5. Experts and stakeholders participation

In the real world, the 'information-implementation' process expected by conservation scientists rarely happens (Cowling, 2005). Building and maintaining the continuum between conservation and land-use planning is not a trivial task, it requires a stakeholder involvement strategy (Knight et al., 2006). The development of the conservation and restoration plan involved vigorous debate among participants. Some participants argued that the planning process was a waste of time as they already knew where the priority areas for conservation were. For them, the priority wasn't to plan but more to negotiate and implement interventions in zones they already identified. Other participants argued that biodiversity conservation couldn't be entirely considered by quantitative targets. Those participants were also reluctant to use a cost-based approach to conservation planning as they felt it would exclude social issues.

Nevertheless, our plan structured arguments for conservation stakeholders and made them spatially explicit. This is useful to advocate for biodiversity conservation, and to negotiate land allocation with other activity sectors such as agriculture. To this purpose, conservation planning products were presented within a wide array of public arenas, including regional administrations (Regional Scientific Council, Departmental Office of Sensible Natural Sites) and protected areas management institutions (National Forest Office, Coastal Conservation Agency).

Despite an invitation to join the conservation planning process, stakeholders from the urban sector did not participate to the development of the conservation plan. One possible explanation is that conservation planners were not perceived as neutral holders of scientific knowledge but rather as competing stakeholders in the land-use planning debate. In addition, other issues are considered more important than conservation in the land-use planning debate, in particular the conflict between the agricultural and the urban sector.

9. Lessons learnt and tips for future applications of the protocol in islands

Our conservation and restoration planning protocol allows the integration of ecological and socio-economic variables within a single spatial planning framework. It provides spatially explicit guidelines for planning conservation and restoration actions inside and outside an existing reserve system. Our study demonstrates the applicability of this approach in Reunion Island. We believe it is applicable in other insular systems. Other socio-economic variables such as social acceptability and the economic value of ecosystem goods and services could easily be integrated in the proposed protocol.

Conservation planning in insular regions must be based upon low-cost and easily accessible data. This data should be representative of biodiversity patterns and processes and have good spatial coverage. To this purpose, developing a basic map of habitats constitutes an efficient solution, before gathering any other biological data.

Past conservation efforts in islands often focused on low-cost zones, i.e. areas without major socio-economic stakes. Consequently, current reserve networks in islands are often biased toward the upland, whereas coastal biodiversity features and processes are not adequately protected. The disconnection among terrestrial, freshwater and marine realms has become an important threat to the persistence of insular ecosystems. Our method helps finding optimal socio-economic and ecological solutions for maintaining those inter-realms linkages across the landscape. Nevertheless complex conservation planning tools such as MARXAN are not mandatory to develop a conservation plan.

Building a conservation plan requires a homogeneous understanding of coupled ecological and social systems, while acknowledging the complexity of such systems and the limitations of our knowledge. By many aspects, islands depend directly on biodiversity for developing sustainable development strategies. It fosters the role of residents in setting conservation planning priorities and participating fully in the development of their islands. Cross-sectoral approaches and involvement of stakeholders are, more than elsewhere, a key component of effective conservation planning in islands.

We consider that our systematic protocol should inform land-use planning but it will never substitute for the land-use planning debate. We believe more in "participation-oriented" approaches rather than pure "GIS product-oriented" procedures to mainstream conservation and restoration issues within land-use planning. Future improvements of the planning protocol should focus on the participation of stakeholders and methods to better-fit conservation planning into existing public decision-making processes

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Appendix A.

See Table A1

Appendix B.

See Table A2

Table A1
Current and initial area of pristine habitats in Réunion Island. Species richness is for vascular plants (from Strasberg et al., 2005).

Habitat classes	Current area (km^2)	Initial area (km^2)	Species richness	Endemic species richness
Erica mountain thicket	9	22	90	38
Pandanus mountain humid thicket	41	41	92	36
Subalpine grassland (dry or wet)	3	3	34	71
Subalpine heath land	153	159	30	25
Subalpine shrub land on lapillis	8	8	30	5
Acacia heterophylla forest	50	105	96	41
Leeward mountain rainforest	89	159	144	67
Leeward submountain rainforest	35	185	142	41
Pandanus humid thicket	20	29	92	38
Windward mountain rainforest	220	259	165	67
Coastal habitats	3	14	35	7
Lava flows	95	97	53	19
Lowland rainforest	75	492	127	29
Lowland open woodland	5	187	41	15
Semi dry forest	35	487	126	30
Subalpine Sophora thicket	2	12	11	7
Submountain mesic forest	34	61	98	33
Wetlands	7	8	26	2
Windward submountain rainforest	108	174	166	58

Table A2
Species targeted in the conservation plan.

Species	Scientific name	Endemism[a]	IUCN WorldRed list status[b]	IUCN regional status[b]	Target (%)
Birds					
	Puffinus lherminieri	B	LC	–	40
	Circus maillardi	B	EN	–	100
	Pseudobulweria aterrima	B	CR	–	100
	Collocalia francica	B, M, Ro	NT	–	60
	Hypsipetes borbonicus	B	LC	–	40
	Pterodroma baraui	B	EN	–	100
	Saxicola tectes	B	LC	–	40
	Terpsiphone bourbonnensis	B	LC	–	40
	Zosterops borbonicus	B	LC	–	40
	Zosterops olivaceus	B	LC	–	40
	Coracina newtoni	B	EN	–	100
	Phaeton lepturus	W	LC	–	40
	Puffinus pacificus	0	LC	–	40
	Phedina borbonica	W	LC	–	100
Reptiles					
	Phelsuma borbonica	B	–	–	100
	Phelsuma (ornata) inexpectata	B	–	–	100
Mammals					
	Mormopterus acetabulosus	0	VU	–	80
Plants					
	Carissa spinarum L.	B, M, Ro	–	CR	100
	Chamaesyce viridula (Cordem. ex Radcl.-Sm.)	B	–	EN	100
	Delosperma napiforme (N.E. Br.) Schwantes	B	–	VU	80
	Dombeya populnea (Cav.) Baker	B, M	–	CR	100
	Gastonia cutispongia Lam.	B	–	CR	100
	Hernandia mascarenensis (Meisn.) Kubitzki	B, M	EN	CR	100
	Obetia ficifolia (Poir.) Gaudich.	B, M, Ro	–	CR	100
	Pemphis acidula J.R. Forst. et G. Forst.	0	–	CR	100

[a] B = Réunion ("Bourbon"), M = Maurice, Ro = Rodrigue, W = West Indian Ocean (including Madagascar), 0 = Other.
[b] CR = seriously on the verge of extinction, EN = threatened of extinction, VU = vulnerable, NT = near threatened, LC = least concern.

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