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## Modelling with stakeholders to integrate biodiversity into land-use planning - Lessons learned in Réunion Island (Western Indian Ocean)

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**Abstract:** This paper considers participatory modelling to integrate biodiversity conservation into land use planning and to facilitate the incorporation of ecological knowledge into public decision making for spatial planning. Réunion Island has experienced rapid urban and agricultural expansion, which threaten its unique biodiversity. In this context, we designed three participatory modelling sequences, involving overall 24 multidisciplinary researchers and stakeholders. The sequences aimed 1) to map land-use and biodiversity, 2) to develop a conservation plan following systematic conservation planning principles using a spatial optimization tool (MARXAN) and 3) to simulate coupled land-use/conservation scenarios using a multi-agent system (MAS). The conservation plan confirms that priority areas for biodiversity protection are located on the coast where rapid land-use changes occur. Nevertheless, stakeholders from the urban and agricultural sector didn't participate to this sequence. Indeed, conservation planning tools are useful to locate conservation priorities but they have to be designed with stakeholders to be accepted as negotiation tool. Besides, the researchers engaged in this second sequence were perceived as conservation stakeholders rather than holders of scientific knowledge. In the third sequence, the researchers involved adopted the stance of facilitating the elicitation of each stake and gathered trust from stakeholders. Overall, we conclude that the participatory development of land-use simulation models should be promoted to explore alternative scenarios for biodiversity conservation with stakeholders. In a situation of land-use conflict, a gradual and sequential participatory modelling approach should be implemented to fit into public decision-making processes.

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January 30, 2009

To:

Tony Jakeman  
Editor-in-Chief  
Environmental Modelling & Software

Dear Editors, Dear Reviewers,

Attached to this letter is the last version of our paper, entitled "Modelling with stakeholders to integrate biodiversity into land-use planning – Lessons learned in Réunion Island".

We did the minor changes you requested. The following section describes our response to the requested minor revision.

Thank you and we look forward to hearing from you.

With best regards,

A handwritten signature in black ink, appearing to be 'Erwann Lagabriele', written in a cursive style with a large loop at the end.

Erwann Lagabriele

## Response to detailed comments:

To facilitate the correction checking, our answers to comments are in *italic*.

Line 34: what does « however this sequence never reached the stakeholders audience » means ?

*We corrected it to: "Nevertheless, stakeholders from the urban and agricultural sector didn't participate to this sequence."*

Line 182 ",," instead of ","

*We corrected it to ",,"*

Line 305: were are the 21 habitats in table 1?

*We completed the sentence as follows "We mapped a system of 44 land-use and habitat classes, including 21 pristine habitats grouped into 7 broader altitudinal groups (Table 1)."*

Line 462 is not it table 2 instead of table 1?

*Yes, we corrected it to "Table 2"*

Line 632: How would I see the 50 % on figure 7?

*We added the following sentence: "Indeed, the exponential shape of the unachieved demand for agricultural land on Figure 7 is due to the concomitant conversion of agricultural land by urbanisation in the lowlands."*

1 **Title:**

2 Modelling with stakeholders to integrate biodiversity into land-use planning –  
3 Lessons learned in Réunion Island (Western Indian Ocean)

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24 **Abstract:**

25 This paper considers participatory modelling to integrate biodiversity  
26 conservation into land use planning and to facilitate the incorporation of ecological  
27 knowledge into public decision making for spatial planning. Réunion Island has  
28 experienced rapid urban and agricultural expansion, which threaten its unique  
29 biodiversity. In this context, we designed three participatory modelling sequences,  
30 involving overall 24 multidisciplinary researchers and stakeholders. The sequences  
31 aimed 1) to map land-use and biodiversity, 2) to develop a conservation plan  
32 following systematic conservation planning principles using a spatial optimization tool  
33 (MARXAN) and 3) to simulate coupled land-use/conservation scenarios using a  
34 multi-agent system (MAS). The conservation plan confirms that priority areas for  
35 biodiversity protection are located on the coast where rapid land-use changes occur.  
36 Nevertheless, stakeholders from the urban and agricultural sector didn't participate  
37 to this sequence. Indeed, conservation planning tools are useful to locate  
38 conservation priorities but they have to be designed with stakeholders to be  
39 accepted as negotiation tool. Besides, the researchers engaged in this second  
40 sequence were perceived as conservation stakeholders rather than holders of  
41 scientific knowledge. In the third sequence, the researchers involved adopted the  
42 stance of facilitating the elicitation of each stake and gathered trust from  
43 stakeholders. Overall, we conclude that the participatory development of land-use  
44 simulation models should be promoted to explore alternative scenarios for  
45 biodiversity conservation with stakeholders. In a situation of land-use conflict, a  
46 gradual and sequential participatory modelling approach should be implemented to  
47 fit into public decision-making processes.

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49 **Key words:**

50 Biodiversity, Land-use management, Conservation planning, Participatory modelling,  
51 Stakeholder, Multi-Agent System, Réunion Island

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## 53 1. Introduction

54 Since the mid 20<sup>th</sup> Century, urbanisation and agricultural expansion have  
55 accelerated all around the world. These trends threaten biodiversity and renewable  
56 resources (Jenkins, 2003, Wilson and Peter, 1988), thereby stressing the need for  
57 linking land-use planning and conservation. Land-use planning guides the  
58 organization of a spatial environment to meet the demands of a society (Ligtenberg  
59 et al., 2004, Verburg et al., 2004). However, land-use plans only recently started to  
60 integrate biodiversity conservation as an explicit goal (Margules and Pressey, 2000,  
61 Driver et al., 2003). Conservation planning, a branch of applied conservation  
62 science, has been specifically developed to integrate biodiversity conservation and  
63 land-use planning within a single framework. Nevertheless, in practice, the two  
64 remain disjointed (Cowling, 2005). In this study, we analyse the association of three  
65 participatory modelling sequences for integrating conservation into land-use  
66 planning.

67 Conservation planning aims to promote the persistence of 'living landscapes' that  
68 integrate biodiversity requirements (Driver et al., 2003, Arendt, 2003). It is  
69 theoretically based on a spatially explicit understanding of complex ecological  
70 systems and their interactions with social systems (Termorshuizen et al., 2007,  
71 Gunderson and Holling, 2002). Conservation planning approaches range on a  
72 continuum from opportunistic to systematic planning approaches (Maruani and Amit-  
73 Cohen, 2007). These methods focus on habitats, species and ecological processes.

74 The Systematic Conservation Planning (SCP) approach developed by Margules  
75 and Pressey (2000) represents a key step towards a spatially explicit, target-driven  
76 planning process for biodiversity conservation. SCP aims to achieve a set of  
77 quantitative conservation targets (e.g. 20% of each habitat in a region) through the  
78 identification of a network of priority areas for conservation, while minimising conflicts  
79 with other land-use (e.g. urbanisation or agriculture) using specialised GIS software  
80 (Moilanen and Kujala, 2008, Ball and Possingham, 2000). Few studies tested the  
81 use of such conservation planning software in a large participatory framework  
82 involving researchers and stakeholders.

83 In the perspective of sustainable development, a participatory approach to  
84 conservation planning must address the behaviour of the social groups involved in  
85 land management (Mathevet et al., 2003). The participation of stakeholders is vital  
86 for the development and implementation of conservation and land-use plans  
87 (Castella et al., 2005, Brown, 2003). As Mathevet et al. (2003) point out, the  
88 placement of conservation areas is usually determined by ad hoc opportunities (e.g.  
89 cheap land), low agricultural potential (e.g. mountainous areas), and moreover,  
90 political will. Conservation planning thus requires the combination of scientific  
91 knowledge with an understanding of the stakeholders involved in the planning  
92 process (Knight et al., 2006).

93 Bousquet et al. (1999) propose an approach based on the development of  
94 models together with stakeholders and researchers to simulate land management  
95 scenarios: the *companion modelling* approach (ComMod). Within the ComMod  
96 approach, the collaborative development of simulation models is a learning process  
97 that leads the participants (including researchers) to explain and share opinions  
98 regarding management options (Souchère et al., 2009, Barreteau et al., 2003). In  
99 this approach, the most important is less the solution but the process leading to it.  
100 Many applications developed under the ComMod theoretical framework are using

101 Multi-Agent Systems (MAS) as simulation tools to implement their models. A MAS  
102 can be defined as a set of agents that interact in a common environment, able to  
103 modify their attributes and their environment (Ferrand, 1997). In environmental  
104 science, agents are often humans interacting with resources distributed in a  
105 landscape. MAS may increase understanding of complex coupled social-ecological  
106 systems (Acevedo et al., 2007), more particularly in the context of land-use planning  
107 (Parker et al, 2002, Etienne et al. 2003, Bousquet and Le Page, 2004,  
108 Schreinemachers and Berger, 2006) and biodiversity planning (Vejpas et al., 2005)

109 This article is divided into eight sections. The first section presents the studied site  
110 and its main challenges in terms of land-use and conservation planning. The second  
111 section summarizes the organisation of the experiment as a whole, whereas the  
112 three following sections are focalizing on each of the participatory modelling  
113 sequences. We discuss the results of the experiments, their impacts and the  
114 participation of stakeholders and researchers in the following section. And finally, we  
115 conclude on the implications of the study for conservation and land-use planning  
116 methodology.

## 117 118 **2. Context and objectives**

### 119 120 **2.1. Spatial planning challenges**

121 The study site for this application is the Réunion Island, a volcanic Island of 2512  
122 km<sup>2</sup> in the Western Indian Ocean (Figure 1). Together with Mauritius and Rodrigues,  
123 it forms the Mascarene archipelago. Réunion Island is a French overseas  
124 department.

125 Elevations range from sea level to 3070 m. Land-use is organised into urban and  
126 agricultural belts in the so-called *lowlands* (<2000 m), and pristine vegetation in the  
127 uplands. At present, more than 80% of the 802 000 inhabitants (INSEE, 2009) live  
128 on the coastal fringe where most of the socio-economic activities are concentrated.  
129 Population increased of 1.5 % per year since 2000 and it is predicted to reach 1  
130 million inhabitants in 2030 (INSEE, 2009).

#### 131 132 [Figure 1](#)

133  
134 The economy of the island has traditionally been based on crop industry, mainly  
135 sugarcane. Since the 1980s, the French government has been pushing the  
136 development of a tourist industry to alleviate unemployment which currently amounts  
137 to more than 40% of the labour force.

138 The economy remains highly dependent on external incomes. Since the 1990s,  
139 as an outermost region of the European Union, Réunion Island has benefited from  
140 European funds for development. This has caused dramatic socio-economic  
141 changes that have impacted the landscapes. For instance, urban areas in Réunion  
142 Island sprawled out by 157% from 1989 to 2002 (Lagabrielle et al., 2007).

143 Concomitantly to the economic development, available land becomes a rare  
144 resource. Landscapes are now expected to fulfil multiple functions and this causes



145 conflicts among stakeholders about land-use planning and management (Van Der  
1 146 Valk, 2002). As the study started, the agricultural sector was asking for roughly 6000  
2 147 extra hectare of land (Département de la Réunion 2006).

4 148 Future challenges for land-use planning in Réunion Island are the control of  
5 149 urban sprawl, the adaptation of infrastructures (particularly roads and water supply  
6 150 devices), the development of public transport, the protection of agricultural lands and  
7 151 biodiversity conservation. Those challenges are listed in the territorial diagnostic  
8 152 produced by the regional council (Conseil Régional de la Réunion, 2009).

11 153 Legally, a regional development plan ("Schéma d'Aménagement Régional":  
12 154 hereafter referred as SAR) rules the allocation of land-use for the whole island, the  
13 155 organisation and the implementation of regional infrastructures including the main  
14 156 roads. Municipal and inter-municipal land-use plans and other regional sector plans  
15 157 (agricultural, industrial, etc.) must be compatible with it. The SAR developed in 1995  
16 158 was under revision as this study was done. A major objective of the 1995 SAR was  
17 159 to control urban sprawl. To this purpose, it allocated an urbanisation quota to each of  
18 160 the 24 municipalities. Most municipalities exceeded by far their quota, causing  
19 161 tensions between the agricultural and the urban sector. This same objective is  
20 162 therefore still valid for the new SAR.

## 25 164 **2.2. Pressures on biodiversity and conservation measures**

27 165 Réunion Island has long been recognised as a global priority for conservation  
28 166 owing to its vulnerability and its high concentration of endemic taxa, especially of  
29 167 plants. Sixty five per cent of the island's 600 species of flowering plants species are  
30 168 endemic (Cadet, 1980). This island lies within the Madagascar biodiversity hotspot  
31 169 (Mittermeier et al., 2005) and a marine biodiversity hotspot (Roberts et al., 2002).  
32 170 Since European occupation in 1665, the pristine vegetation cover in the lowlands  
33 171 has been almost fully converted, except on harsh slopes (Gigord et al., 1999,  
34 172 Strasberg et al., 2005). Increasing anthropogenic pressure has already led to the  
35 173 extinction of 30 of the 45 vertebrates species (Cheke, 1987).

38 174 Habitat conversion by urbanisation or agriculture, and habitat degradation by  
39 175 invasive alien species (for instance *Clidemia hirta* and *Acacia mearnsii* among 62  
40 176 species considered as highly invasive) are the main threats to native biodiversity  
41 177 (Baret et al., 2006). 90 % of the lowland habitats have been cleared or replaced by  
42 178 alien vegetation (Strasberg et al, 2005) (Table 1). Urbanisation pressure is extremely  
43 179 high on remnant pristine habitats in the lowlands, while native forest clearing for  
44 180 cattle breeding is a major threat to biodiversity in the uplands.

### 47 181 48 182 Table 1

51 183  
52 184 Because of its steep land environment, one third of the island is still covered by  
53 185 native vegetation (Table 1), whereas other islands of the Mascarene archipelago  
54 186 almost lost their pristine vegetation cover (Strasberg et al., 2005). Therefore,  
55 187 Réunion Island is now responsible for the conservation of terrestrial biodiversity in  
56 188 the whole Mascarene region.

189 Since the creation of a National Park in 2007, 43% of the island's surface is  
190 protected within statutory reserves (i.e. areas specifically dedicated to biodiversity  
191 conservation). The distribution of the protected areas network is biased toward the  
192 uplands: the mean altitude of protected areas is 1306 m versus 873 m for the whole  
193 island. This lack of protection in the lowlands is a consequence of a combination of  
194 factors including the persistence of fewer pristine lowland habitats and higher  
195 pressure from other activity sectors (urbanisation and agriculture). Consequently, the  
196 future of biodiversity in Réunion Island now depends straight on land-use planning in  
197 the lowlands.

### 2.3. Study objectives

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199  
200 In line with the current and future development challenges in Réunion Island, the  
201 operational objectives of this study were i) to identify priority areas for conservation,  
202 ii) to provide guidelines for implementing conservation actions outside existing  
203 reserves while dealing with increasing pressuring factors in the lowlands; iii) to  
204 "accompany" the conservation sector to negotiate land-use planning and decision-  
205 making, more particularly in relation to the new regional land-use plan and the  
206 management plan of the National Park, and iv) to explore alternative scenarios for  
207 land-use and conservation planning. Alongside with those objectives, the overall goal  
208 was to test different approaches to bridge the scientific and operational communities  
209 by bringing multidisciplinary scientists and stakeholders to collaborate around the  
210 participatory development of spatial models for land-use and conservation planning.

### 3. Development and organisation of the participatory modelling sequences

211  
212  
213 This section briefly presents the organisation, objectives and participants of the  
214 participatory modelling sequence. Basically a participatory modelling sequence  
215 consists in building a model (in our case a map or a computer tool) and using it to  
216 perform a diagnostic or to simulate scenarios interactively with stakeholders. Those  
217 stakeholders are defined as individuals, groups or organisations that can affect or be  
218 affected by the implementation of the spatial plan. In our study, those stakeholders  
219 belong to three activity sectors: agriculture, conservation and urbanisation. In the  
220 following text, the term "regional" means the whole Réunion Island.

221 - The objective of the first sequence (hereafter S1) was to map biodiversity and  
222 land-use using a Geographic Information System (GIS). A first group of participants  
223 specialized in conservation issues (hereafter G1) mapped biodiversity and a second  
224 group (G2) mapped the land-use. G1 and G2 had a common core of scientist  
225 participants. G1 was a team of 10 persons, who were mainly scientists (geographer,  
226 anthropologist, agronomist, modeller and ecologist), but also staff of the National  
227 Parks authority. G1 was primarily interested in assessing biodiversity representation  
228 within the current network of protected areas. G2 gathered a multidisciplinary team  
229 of 11 researchers (modellers, ecologist, sociologist, anthropologist, urban and rural  
230 geographers and computer scientists) and 6 members of extension and support  
231 services staff for rural development.

232 - The second sequence (S2) aimed to identify a complementary network of  
233 priority areas for biodiversity conservation using a spatial optimization GIS tool  
234 (MARXAN). It was done by the G1 group.

235 - The third sequence (S3) aimed to support the SAR revision by developing a  
1 236 ComMod approach for land-use foresight (Botta et al. 2009). We used an agent  
2 237 based model developed in two steps. A first prototype was built by the G2 group. It  
3 238 was then adapted by a second team including part of G2 (6 persons among which 4  
4 239 researchers) and the group in charge of the SAR revision (4 persons: coordinator,  
5 240 urban planner, and 2 engineers specialized in environment and GIS). Hereafter we  
6 241 refer to this group as G3.  
7 242

8  
9 242 Besides, the sequence S3 was partly done in collaboration with the larger  
10 243 institutional process of the SAR revision, which gathered 200 stakeholders from  
11 244 regional institutions and of the civil society. The SAR revision associated regional  
12 245 elected representatives together with representatives of the agricultural industries  
13 246 (cane and cattle), urban planners and conservation institutions (National Park,  
14 247 National Forest Office, Regional Environmental Affairs, etc.). The SAR revision was  
15 248 organised in three stages. In the 'diagnostic' stage, stakeholders identified the main  
16 249 challenges for the future of Réunion Island. In the 'scenario development' stage, they  
17 250 extracted and ranked a subset of key challenges and built four contrasted land-use  
18 251 planning scenarios by ranking those challenges (Table 2). Lastly, based on the  
19 252 debate emerging from the simulation of those scenarios in collaboration with S3,  
20 253 they identified the main stakes and means of action to identify the most appropriate  
21 254 future land-use for the Island.  
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## 27 256 [Table 2](#)

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31 258 We assessed the impacts on biodiversity of land-use scenarios developed in S3.  
32 259 That simulation only involved researchers. We intended it to be participatory but the  
33 260 group in charge of the SAR revision didn't want to discuss conservation issues  
34 261 collectively, preferring to deal directly with representatives of the strongest  
35 262 conservation stakeholders: the Regional Environmental Affairs (hereafter DIREN).  
36  
37 263

## 38 39 264 **4. Sequence 1: Participatory mapping of land-use and biodiversity**

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41 265

### 42 266 ***4.1. Objectives and participants***

43

44 267 In this first sequence, the objective was to develop a map of ecological habitat  
45 268 units, compatible with conventional land-use maps of urban and agriculture areas.  
46 269 Such maps facilitate the integration of conservation issues into the land-use debate  
47 270 and act as good surrogates for biodiversity as a whole (Lombard et al., 2003).  
48 271 Additional maps on conservation-related issues (species distribution for instance)  
49 272 were also collected during the workshop.  
50  
51 273

### 52 274 ***4.2. Material and methods***

53

54 275 We integrated expert judgements with field survey, remote sensing data and GIS  
55 276 analysis to develop a combined land-use and biodiversity map during a one-day  
56 277 workshop.  
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278 Pristine habitats had been mapped by Strasberg et al. (2005) based on field  
279 work, expert judgment, basic GIS data (slope, altitude and rainfall) and aerial  
280 photography analysis. The map of urban areas was provided by the Regional Urban  
281 Planning Agency (AGORAH). Agricultural categories (cane, other crops and  
282 pastures) had been previously mapped with agriculture experts using remote  
283 sensing and GIS data. We combined those three maps following a set of rules  
284 defined with the participants.

285 Each feature of the map - including urban and agricultural areas - was attributed  
286 a transformation status by conservation experts. The transformation status  
287 categories were derived from Strasberg et al. (2005) and Baret et al. (2006): *extant*  
288 (*i.e.* pristine), *invaded* (pristine remnants but alien species covering more than 50%  
289 of the under storey and more than 90% of the canopy), *transformed restorable*  
290 (secondary vegetation and agricultural areas) and *irreversibly transformed* (urban  
291 areas) (Figure 2a; Table 1).

292 We also collected spatial datasets on species distribution (Figure 2b). Species  
293 data on plants and animals were provided by experts who collected them on the field  
294 or mapped them using aerial photography.

295 In addition, a map of the *spatial components of biodiversity processes* (SCBPs)  
296 was derived with conservation experts based on GIS analysis and a literature review  
297 (Lagabrielle et al., 2009) (Figure 2c). SCBPs are defined as geographic zones  
298 supporting key ecological processes (such as movements of endemic species) and  
299 evolutionary processes (such as speciation processes along altitudinal gradients)  
300 (Figure 2c). Lagabrielle et al. (2009) provide a detailed description of the mapping  
301 method. The transformation status of SCBPs ranked from *extant* in pristine habitats,  
302 to *restorable* in crop or secondary vegetation and *lost* in urban areas.

## 303 304 [Figure 2](#)

### 305 306 **4.3. Outputs**

307 We mapped a system of 44 land-use and habitat classes, including 21 pristine  
308 habitats grouped into 7 broader altitudinal groups (Table 1). This was the maximum  
309 number of extractible classes. Those classes were then aggregated into broader  
310 categories for the next modelling sequences: natural, agricultural and urban, as  
311 shown on Figure 1. More details on the current and past status of ecological habitats  
312 are provided in Table 1. In addition, we collected GIS layers on 25 indigenous  
313 species, including endemic plants (Figure 2b), the breeding areas of five oceanic bird  
314 species and the distribution areas of nine endemic forest birds, two reptiles and one  
315 bat species. Five spatial components of biodiversity processes (SCBPs) were  
316 mapped: the oceanic-terrestrial interfaces, the riverine corridors, the habitat  
317 interfaces, the topographic unit boundaries, and the lowland-upland gradients  
318 (Figure 2c).

319 A regional network of 23 large scale natural corridors linking the lowlands to the  
320 uplands was designed to guarantee the persistence of all extant SCBPs (Figure 2d).  
321 Those corridors encompass a maximal amount of pristine habitats from the sea level  
322 to the summits of the island (Lagabrielle et al., 2009). Those spatial features are

323 important to conserve ecological linkages between the oceanic and the terrestrial  
324 domain.

325 The discussions among participants focused mainly on the definition of habitat  
326 categories compatible with operational land-use planning. For instance, the  
327 categorisation of agricultural activities was heavily discussed, some stakeholders  
328 willing to impose a very detailed categorisation incompatible with the objectives of  
329 the project. The selection of data sources was discussed as well. Each sector  
330 wanted to impose its own GIS layer, which resulted in major overlaps among layers.  
331 For instance, in the lowlands, urban areas overlapped with large agricultural areas  
332 mapped by stakeholders from the agricultural sector. To solve such overlay conflicts  
333 (i.e. sites having different land-use in at least two layers), participants agreed on a  
334 specific priority order with urban areas superimposing to all other categories. The  
335 final habitat map is thus a negotiated combination of all GIS layers provided by the  
336 different sectors.

337 It soon appeared obvious that through their definition of the land-use system,  
338 each sector was trying to defend its own mental categorisation of the landscape. The  
339 land-use categories representing ecological habitats, proposed by the  
340 conservationists, were not well understood by the other participants who found them  
341 too complex and detailed. Divergences among participants also emerged when  
342 attributing a “transformed but restorable” status to areas suitable for agriculture in the  
343 uplands. The attribution of a “pristine” status to areas located outside the margin of  
344 protected areas also involved heavy debates between conservationists and  
345 participants from the agricultural sector. Agricultural stakeholder seemed to fear that  
346 conservationists implement conservation measures that prevent them from  
347 cultivating their land in the future.

## 348 349 **5. Sequence 2: Participatory conservation planning**

### 350 351 ***5.1. Objectives and participants***

352 In this second participatory modelling sequence we followed a systematic  
353 conservation planning approach (Cowling et al., 2003) to identify an optimal spatial  
354 network of priority areas for conservation. Each biodiversity feature was assigned  
355 quantitative conservation targets. An average surface target of 30 % of their initial  
356 area (e.g., before human colonization) was assigned to each pristine habitat  
357 category. The distribution of habitats before human colonization was developed by  
358 Strasberg et al. (2005) using expert knowledge and GIS data on altitude and rainfall.

### 359 360 ***5.2. Material and methods***

361 We used the conservation planning software MARXAN (Ball and Possingham,  
362 2000), and its interface CLUZ (Smith, 2004) in Arcview 3.2 (ESRI, Redlands,  
363 California) to develop the conservation plan. MARXAN allows the users i) to assess  
364 the contribution of a reserve system to achieve conservation targets and ii) to select  
365 a near-optimal network of complementary reserves that achieve conservation targets  
366 (Sarkar and Margules 2002). This complementary reserve network contributes to the  
367 achievement of conservation targets. Consequently, it should be conserved in the  
368 future, in addition to the current reserve network.

369 MARXAN software is designed with the use of stochastic optimization routines  
1 370 (simulated annealing, Kirkpatrick, 1983). Following an iterative selection process, the  
2 371 algorithm attempts identify a near-optimal reserve system called *solution*, by  
3 372 minimising its total cost (Possingham et al., 2000). Planning units frequently  
4 373 integrated within *solutions* are the most *irreplaceable* (MARXAN sensu).

6 374 The costs and the number of runs have been calibrated heuristically with  
7 375 conservation scientists and adjusted along the simulation sequence (see Ardron et  
8 376 al. (2008) for more details about MARXAN parameters settings). In our case, the  
9 377 costs used for the optimization were non-monetary values estimated on the basis of  
10 378 their relative importance by scientists from G1. As explained on Figure 3, three  
11 379 categories of cost were estimated:

- 14 380 - First, the “fine” to be paid if a conservation target is not achieved. We  
15 381 attributed a prohibitive value of 10 million per biodiversity feature to this  
16 382 parameter. Thus we ensured that each solution adequately represented all  
17 383 features.
- 19 384 - Second, the cost of each planning unit per km<sup>2</sup> per year. To calculate this  
20 385 parameter, we developed a synthetic index of conservation costs (SICC). The  
21 386 SICC is calculated by summing the following variables detailed in Table 3:  
22 387 implementation cost, invasive plants control cost, restoration cost and  
23 388 conversion pressure cost. The resulting SICC in Réunion Island varied from 3  
24 389 (attractive) in the uplands, to 37 (repulsive) in the lowlands.

### 30 391 [Table 3](#)

- 33 393 - Third, the boundary length cost which is the cost associated with the  
34 394 management of reserve boundaries per km per year. Increasing this cost  
35 395 promotes the compactness of the reserve network identified.

37 396 The model validation was done by G1 members, by comparing the final map of  
38 397 conservation priorities to their own mental representations of conservation priorities  
39 398 in the landscape.

41 399 For the purpose of the analysis, the planning domain was divided into square  
42 400 *cells* of 4 ha, similar to those used in the MAS simulation model (see Section 6). The  
43 401 4 ha resolution was chosen as the best compromise between data processing  
44 402 constraints, spatial resolution of input data and management requirements.

### 48 404 [Figure 3](#)

## 52 406 **5.3. Outputs**

53 407 The main output of the modelling sequence was a map of priority areas for  
54 408 conservation actions. This map shows the distribution of highly irreplaceable  
55 409 conservation sites and corridors (Figure 7). The priority areas encompassed 1508  
56 409 km<sup>2</sup> of land (Figures 7b and 7c) of which approximately 500 km<sup>2</sup> is not currently  
57 410 protected and should be allocated to some form of conservation management to  
58 411 ensure the persistence of the documented biodiversity of Réunion Island.  
59 412

413 The development of the modelling sequence involved vigorous debate among  
1 414 participants. Some participants argued that the modelling process was a waste of  
2 415 time as they already knew where the priority areas for conservation were. For them,  
3 416 the problem was not to know where to intervene but rather how to negotiate and  
4 417 implement interventions. The concept of conservation targets also raised polemics  
5 418 among the group, as participants argued that biodiversity conservation couldn't be  
6 419 resumed to quantitative objectives. Those participants were also reluctant to use a  
7 420 cost-based approach to conservation planning. Given this lack of global buy-in from  
8 421 the participants, we discarded the idea of involving land-use stakeholders in the  
9 422 conservation planning process as initially stated. Despite disagreements about the  
10 423 method, all participants agreed about the output map of priority areas.

13 424 Finally, the map of priority areas for conservation was presented within a wide  
14 425 array of public arenas, including regional administrations (Regional Scientific  
15 426 Council, Departmental Office of Sensible Natural Sites) and state institutions  
16 427 (National Forest Office). Feedbacks from those institutions are discussed in Section  
17 428 7.

## 20 429 21 430 **6. Sequence 3: Participatory land-use planning using a scenario simulation** 22 431 **model**

### 23 432 24 433 **6.1. Objectives and participants**

25 434 The main purpose of this third modelling sequence was to illustrate the need for  
26 435 compromises among land-use sectors with a land-use simulation tool that would be  
27 436 accepted by representative of each sector, rather than to find new results in terms of  
28 437 land-use dynamics. To do so, we choose to involved stakeholders from the  
29 438 beginning of the modelling sequence.

30 439 We built a multi-agents model (MAS) with stakeholders and researchers, called  
31 440 'DS'<sup>1</sup> to simulate prospective land-use scenarios (Botta et al., 2009; Daré et al.,  
32 441 2008). To this purpose, we adopted a ComMod approach, organised into iterative  
33 442 cycles. During the model development phase, those cycles involved the progressive  
34 443 definition of hypothesis on the structure and dynamics as well as of indicators.  
35 444 During the simulation phase, planning hypotheses identified by the participants in the  
36 445 diagnostic stage of the SAR revision process were progressively translated within  
37 446 the G3 group into simulation scenarios. The final model outputs were then evaluated  
38 447 by all the participants of the SAR revision process.

### 39 448 40 449 **6.2. Material and methods**

41 450 The MAS modelling process focused on the interactions between three major  
42 451 classes of land-use: natural, agricultural, and urban. Considering that urban sprawl is  
43 452 driven by demography, the urban expansion is driven by the population dynamics  
44 453 (growth) and its distribution on the territory. The final land-use simulation model is  
45 454 therefore composed of two coupled dynamics: a population dynamic (evolution,  
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58 <sup>1</sup> DS acronym stands for Domino (the name of the project) and Smat (the name of a first multi-agent  
59 model prototype we developed for the population dynamic)  
60  
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65

455 density and distribution of the population) and a land-use dynamic (land-use  
1 456 changes).

2  
3 457 The first stage in the elaboration of the MAS simulation model was to determine  
4 458 and specify its social and spatial entities. The second stage of the MAS modelling  
5 459 was then to define their organisation and the dynamics of their interactions. This  
6 460 entailed the sequencing and ordering of the interactions among social agents and  
7 461 spatial entities. To this purpose, the group of modelling participants was split into  
8 462 three sub-groups representing the agriculture, urbanisation and conservation  
9 463 sectors. Each group modelled a specific set of dynamic interactions related to its  
10 464 sector and a first prototype of MAS was then assembled and discussed. The third  
11 465 stage involved the co-construction of land-use scenarios and their translation in the  
12 466 model (Table 2).

13  
14  
15 467 We implemented the complete DS model (David et al., 2007) on the multi-agent  
16 468 simulation platform GEAMAS-NG (Payet et al., 2006) developed at the University of  
17 469 Réunion Island. We had to detail two kinds of entities: the agents representing social  
18 470 entities and the elements of their environment representing spatial entities. All the  
19 471 DS entities that we describe in the following paragraphs are represented on the UML  
20 472 diagram on Figure 4.

#### 23 473 24 25 474 [Figure 4](#)

26  
27 475  
28 476 The *environment* is composed of elementary spatial square units of land that we  
29 477 call *cells*. For this application we used 4 ha *cells* (63245 cells to cover the whole  
30 478 island), but the model allows the user to perform simulations (for the whole island or  
31 479 in sub-regions of the island) with other *cells* size.

32  
33  
34 480 The population dynamic is obtained through interactions between three kinds of  
35 481 agents: *region*, *micro-region*, and *land parcels*. For this application, there was only  
36 482 one *region* agent (the Island) and four *micro-regions* agents (Northern, Southern,  
37 483 Eastern and Western micro-regions of the Island). The *land parcels* agents are as  
38 484 many as the cells of the environment. Note that the *land parcels* and the *cells* are  
39 485 different entities: the first ones are agents, with an internal behaviour, whereas the  
40 486 second ones are simple objects of the environment that can be manipulated by the  
41 487 agents of the system. Those agents run on demographic parameter values (birth,  
42 488 death, and immigration rates) provided by the French National Institute of Statistics  
43 489 and Economic Studies (INSEE). At the beginning of the simulation the *land parcels*  
44 490 agents are initialized with an initial population (802 000 in 2006) and with local birth  
45 491 rate (1.8 % in 2006) and death rates (0.5 % in 2006). During the simulation each  
46 492 *land parcel* agent calculates a new population that is communicated to its belonged  
47 493 agents *micro-region* and *region*. The population coming from each *land parcel* is  
48 494 then modified by migration and densification processes at the micro-regional and  
49 495 regional levels. This enables the *region* agent to calculate the new population of the  
50 496 whole island and to spread up this population to the *land parcels* according to the  
51 497 sprawling and densification parameters defined by users in the simulation scenario.

52  
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56 498 Land-use dynamic is supervised at regional level by three macro-agents that  
57 499 interact with the *cells* of the environment. They represent respectively the *urban*, the  
58 500 *agricultural* and the *natural* sector. Those agents act as global surrogates for the real  
59 501 process of land-use change, which results from the decisions of several individual  
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502 land owners. Although this modelling choice seems to oversimplify the system, it was  
1 503 accepted by the G2 participants as a solution to overcome the disagreement among  
2 504 them on the way to go more into details, and it avoided a tricky calibration process.

4 505 At the beginning of a simulation, each *cell* is initialized with a unique land-use  
5 506 informed by the land-use map developed in the modelling sequence S1: natural,  
6 507 agricultural or urban. Each *cell* is also attributed a suitability score for each activity  
7 508 (conservation, urbanisation and agriculture). These suitability scores were scaled as  
8 509 follows: null, low, medium and high. And they were assigned to the *cells* by using a  
9 510 configuration method that consisted in initializing the *cells* with information coming  
10 511 from several semantic colour maps of the island (Payet et al., 2007); each colour  
11 512 corresponding to one of the four possible suitability scores. Suitability for  
12 513 conservation was set according to the transformation status of habitats, ranking from  
13 514 *irreversibly transformed* (suitability = null) to *pristine* (high) (see Section 5 and Figure  
14 515 2a). The suitability map for urbanisation was developed by the urban planner of the  
15 516 team in charge of the SAR revision. Suitability for agriculture was defined by  
16 517 agricultural stakeholders of G2 based on a comprehensive GIS analysis of  
17 518 agronomic factors (soil, slope, accessibility, etc.). The last two suitability maps were  
18 519 also used to calculate the “conversion pressure cost” layer in MARXAN (Table 3).

22 520 Each year, during simulation, the three macro-agents reassess and convert the  
23 521 state of the *cells* to the benefit of their activity sector. Each macro-agent tries to  
24 522 change land-use in some of the *cells* that it considers to be the most suitable for  
25 523 urbanization (urban macro-agent), agriculture (agriculture macro-agent) or  
26 524 conservation (conservation macro-agent). Such changes are operated in order to  
27 525 reach sectoral objectives fixed by the simulation parameters and the evolution of the  
28 526 population dynamic. If more cells than required to satisfy one macro-agent have a  
29 527 same best suitability score, the choice of the cells to be changed by the concerned  
30 528 macro-agent is randomized.

34 529 Land-use restrictions are implemented to constrain land-use changes. Globally,  
35 530 we considered that *urban* is an irreversible state and a *cultivated cell* cannot become  
36 531 again a *natural cell*, i.e. ecological restoration isn't possible. A *cell* flagged with a  
37 532 “restriction” attribute is a *cell* where conversion is no longer possible. The  
38 533 *conservation* macro-agent implements such flags in *cells* suitable for conservation.  
39 534 Other macro-agents may not respect those flags depending on the simulation  
40 535 settings, i.e. they can ignore protected areas proposed by the *conservation* macro-  
41 536 agent. All those settings have been discussed with the participants from G3.

44 537 Through land-use changes, the *agricultural* and *conservation* sector macro-  
45 538 agents try to achieve a surface target. To achieve this target, each sector is allocated  
46 539 a yearly conversion quota. For instance, in the Trend-oriented scenario, the  
47 540 *agricultural* sector macro-agent targeted a stable surface and was allowed to convert  
48 541 a quota of 1000 ha of land to agriculture each year during the 25 years of the  
49 542 simulated scenario (2005-2030). The conversion quota was set for each sector and  
50 543 for each scenario with the participants based on the spatial objective of each sector.  
51 544 Those objectives had been derived from the SAR scenarios and reflected distinct  
52 545 development options for the Island.

56 546 The target for the *urban* sector macro-agent is expressed as a human density  
57 547 threshold per cell. Once this threshold is reached, the *urban* macro-agent tries to  
58 548 convert *non-urban* cells to *urban* cells. This constitutes the main coupling point  
59 549 between the land-use dynamic and the population dynamic: the human density

550 threshold is reached by the population dynamic agents and then acts as a stimulus  
1 551 leading to the urbanisation of *non-urban* cells by the *urban* macro-agent of the land-  
2 552 use dynamic. More details about the population dynamics and its link with the  
3 553 urbanisation process at various levels can be found in Botta et al. (2009).

5 554 The set of land-use conversion rules and the priority order among social agents  
6 555 for allocating cells was defined by the user at the beginning of the simulation. For the  
7 556 simulations presented in this article, the priority order among sectors was: *Urban* >  
8 557 *Agricultural* > *Conservation*. Following the opinions of G2 members, this priority  
9 558 order is conform to real spatial planning processes in Réunion Island.

12 559 At the end of each simulation, the model provides outputs and indicators: i) log  
13 560 files containing information on the simulation process (for instance, achieved target  
14 561 for the agricultural sectors in ha), ii) graphics showing compared evolutions of the  
15 562 three land-use categories (in ha) and iii) maps showing spatial data such as the  
16 563 « new » land-use map of the island (exportable in GIS grid format).

18 564 An interface allows the user to build a scenario of simulation (for instance, a  
19 565 rapid urban sprawl combined with a complete conservation of pristine habitats), by  
20 566 initializing a specific set of parameters (see Figure 5). In the sequence S3, the  
21 567 scenarios were inherited from the participatory process developed among the large  
22 568 group of SAR revision participants. G3 members adjusted the model prototype to  
23 569 enable it to translate these scenarios into simulations in DS. DS was then used to  
24 570 assess the impacts of the various scenarios on land-use and biodiversity up until  
25 571 2030, with a yearly temporal resolution (Table 4).

28 572  
29 573 [Figure 5](#)

31 574  
32 575 [Table 4](#)

34 576  
35 577 The four main scenarios were namely the *Trend* scenario, the *Urbanisation-*  
36 578 *oriented* scenario, the *Nature-friendly* scenario and the *Economy-oriented* scenario.  
37 579 The first scenario depicted what would happen if there was no change in the current  
38 580 territorial dynamics. The three other ones referred to the main challenges for the  
39 581 Island: rationalising urban sprawl by housing one million of inhabitants, conserving  
40 582 resources, developing its economy. Each of these scenarios explored what would  
41 583 happen if one of these challenges was prevailing on the others. They are resumed in  
42 584 Table 2, for more detail see Conseil Régional de la Réunion (2009).

43 585 All scenarios had to be simplified to be translated into DS. For example, social or  
44 586 transportation aspects were ignored as they were impossible to represent in DS. The  
45 587 stakeholders validated the outputs of the model based on their plausibility, and more  
46 588 so by looking at their differences when compared to the outputs of the trend  
47 589 scenario.

### 54 590 55 591 **6.3. Outputs**

56 592 As expected, all four scenarios simulated that the agricultural sector is hugely  
57 593 impacted by urbanisation. By domino effect, this urbanisation in the lowlands affects

594 pristine habitat in the uplands as the agricultural sector, to maintain its surface,  
1 595 convert natural landscapes on its upper margins. DS model reproduces such land-  
2 596 use competition mechanism and its indirect impacts on biodiversity in Réunion  
3 597 Island.

5 598 The best SAR scenario for biodiversity was as expected the *Nature-friendly* one  
6 599 (Figure 6a), whereas the *Economy-oriented* scenario (Figure 6b) was the worst. The  
7 600 *Economy-oriented* scenario involved high urban densification and a surface target for  
8 601 the agricultural sector of 25% more of surface in the next 15 years (Table 4). This  
9 602 scenario would lead to the conversion of 3% of the current pristine habitats and  
10 603 would impact more than 15% of the recorded distribution of indigenous species.

### 604 [Figure 6](#)

17 607 In the *Urbanisation-oriented* scenario, the loss of agricultural land due to  
18 608 urbanisation was compensated by the cultivation of large natural areas in the  
19 609 uplands. Although it did not implicate a high rate of conversion of pristine habitats,  
20 610 the *Trend scenario* was associated with a major socio-economic crisis due to  
21 611 insufficient housing capacities and weak governance of land-use development  
22 612 (uncontrolled urban sprawl) (Table 4).

25 613 As the modelling process moved toward the regional land-use planning arena  
26 614 (SAR), the composition of the G2 participatory group broadened, with new  
27 615 participants such as members of extension and support services for urban  
28 616 development joining the team. At the same time, conservationists, particularly those  
29 617 from G1 group, were excluded from the simulation process. This resulted in the  
30 618 conservation sector and certain important agricultural role players being absent from  
31 619 the G3 group. To build the final regional plan, the SAR team organised later some  
32 620 bilateral groups with specific theme (agriculture; natural resources, etc).

35 621 To motivate their decision to exclude conservationists, the group in charge of the  
36 622 SAR revision argued that the conservation stake would not be discussed collectively  
37 623 but rather between themselves and the representative of the strongest conservation  
38 624 representative: the DIREN. Finally, the conservation planning products resulting from  
39 625 the two first sequences were not used for the SAR revision process. The decision of  
40 626 not integrating the outputs of the conservation plan in the SAR was perceived as a  
41 627 failure by the conservationists involved, and raised question about the “return on  
42 628 investment” of the conservation planning approach implemented in Sequence 2.

45 629 Independently from G2 and G3, researchers from the G1 team then decided to  
46 630 simulate alternatives to the SAR *Trend* scenario in order to assess the impacts of  
47 631 implementing the additional 500 km<sup>2</sup> reserves network (i.e. irreplaceable sites and  
48 632 conservation corridors) identified in Sequence 2. Results show that implementing  
49 633 those reserves would result in a 2100 ha loss for the agricultural sector (7 % of the  
50 634 current agriculture area). However, the simulation also revealed that, in addition to  
51 635 the land conversion restriction imposed by the new reserves in the uplands,  
52 636 concomitant urbanisation in the lowlands would explain approximately 50% of this  
53 637 loss (Figure 7). Indeed, the exponential shape of the unachieved demand for  
54 638 agricultural land on Figure 7 is due to the concomitant conversion of agricultural land  
55 639 by urbanisation in the lowlands.

59 640

## Figure 7

The results of the sequence S2 that showed the necessity of expanding protected areas in the lowlands and the results of S3 showing the impacts of the SAR scenarios on biodiversity were presented to the staff of the National Park and National Forest Office. Recently, the scientific unit of the National Park contacted G1 to prioritize sites for conservation actions within the boundaries of the National Park.

### **7. Discussion: Can participatory modelling promote integrating conservation with land-use planning?**

#### ***7.1. Impacts of the modelling sequences on the integration of conservation with land-use planning***

The impacts of a participatory modelling process remain difficult to evaluate because they are the result of complex interactions and can't therefore be analysed independently, using single indicators of success (Ludwig, 2001). Here, we discuss them based on the observations made by the participatory modelling investigators during and 12 months after the process.

Jiggins and Röling (2002), distinguish three categories of participatory modelling processes depending on their expected impacts : i) generating social robust knowledge for effective and efficient policy-making, ii) enhancing social learning and capacity building for practical problem-solving and, iii) empowering and advocating for socio-political transformation. Although each of our modelling sequence combines several of these objectives, we can identify a dominant one. The modelling sequences S1 and S2 relate mostly to the first category where scientific knowledge is assumed to lead toward better decision making if it can be socially appropriated by the stakeholders. These sequences partly answer the two first objectives of this study: the identification of priority areas for conservation and the provision of guidelines for implementing conservation actions outside existing reserves while dealing with increasing pressuring factors in the lowlands. The type of knowledge represented in the models is mostly scientific. The last sequence S3 rather belongs to the second category, where the investigator of the modelling process is a facilitator to social-ecological learning, opinion sharing and elicitation toward better management decision. The participants to the sequence S3 have mostly learned about each other and less about their own practices.

Learning and awareness-raising were important outcomes of the modelling sequences (Armitage et al., 2008). They led to the development of new knowledge about the territory and its biodiversity in Réunion Island. The participants developed a better understanding of the system, similar to what Bolte et al. (2007) observed in their experiment. For instance, the conservation planning sequence demonstrated the risks associated with the lack of biodiversity protection in the lowlands. DS model reproduced their understanding of the impacts of each sector (agriculture, urbanisation and conservation) on the landscape and on biodiversity: It showed the cascading effects of urbanisation: the conversion of agricultural land and finally the conversion of pristine habitats. We also assessed the impact of implementing additional protected areas on the agricultural sector (Figure 7).

687 By measuring trade-off between the conservation and the agricultural activities in  
688 the landscape, we were able to extend our answer to the 4th objective of our study:  
689 the exploration of alternative scenarios for land-use and conservation planning.  
690 Trade-offs shown in Figure 6 are reasonably plausible. Nevertheless, the impacts of  
691 the economy-oriented scenarios on species seem overestimated as some individuals  
692 might persist within small vegetation patches in cultivated cells. However, on the  
693 long term such rates of species distribution erosion are likely to occur. 30 out of 45  
694 vertebrate species went extinct since human occupation of the island (Cheke, 1987).

695 As a positive externality of the participative modelling sequences, the  
696 participants learned technically about the co-construction of GIS layers on  
697 biodiversity and land-use, and more generally about the use of a spatial simulation  
698 model. To develop the MAS model or to run MARXAN, the participants stated their  
699 objectives and preferences for their activity sector in quantitative terms, for instance  
700 by setting spatial targets for agriculture expansion. This process is called “elicitation”  
701 by Ferber and Guerin, 2003. They had to share those statements with other  
702 participants, thus clarifying and structuring the debate on land-use and conservation  
703 planning issues.

704 The participants learned about the other activity sectors mostly during the third  
705 modelling sequence, by sharing knowledge with the other participants. They were  
706 more able to better understand the “mechanics” of the other sectors (also called  
707 “decentration” process by Ferber and Guerin, 2003). For instance, the participants  
708 better understood the pressures exerted by urban sprawl on the agricultural sector.  
709 In return, the complexity of urban planning was made evident to all participants.

710 The last objective: “to ‘accompany’ the conservation sector to negotiate land-use  
711 planning and decision-making, more particularly in relation to the new regional land-  
712 use plan and the management plan of the National Park” was the less achieved of  
713 our objectives, as all the representatives of the conservation sector were evinced  
714 from the S3 sequence. Although the results of the three sequences were presented  
715 to other conservation stakeholders afterward, they didn’t seem to use this knowledge  
716 within the SAR revision process. Nevertheless, the National Park is interested in  
717 using the conservation plan developed in S2 for prioritizing conservation sites within  
718 its boundaries.

719 Globally, the debates occurring during the three modelling sequences  
720 highlighted that the interactions occurring among the activity sectors involved in  
721 spatial planning cannot be resumed to spatial processes. The whole study also  
722 made evident that land-use policies and conservation are intrinsically interlinked.  
723 Those results question the utility of conservation planning when the conservation  
724 plan is undertaken independently from land-use planning.

## 7.2. *The value of the participatory modelling process*

727 The value of the participatory modelling process always depends on the  
728 willingness of participants to really engage in it. For instance, the national forest  
729 office (ONF) representative refused to participate. This would have weakened its  
730 position for negotiating the future institutional mandate of the ONF in a context of  
731 institutional competition with the National Park. Although the participatory modelling  
732 sequences intended to reduce information asymmetry among stakeholders from a  
733 range of activity sectors we must acknowledge that part of the information wasn’t

734 elicited and remains cryptic. Most institutional participants never revealed their  
1 735 strategy, indicating that tensions for power continue to cloud participatory  
2 736 experiments in accordance with stakeholders' respective agendas (Wallace, 2003).

3  
4 737 The participatory modelling sequences aimed to link land-use planning with  
5 738 biodiversity conservation and to promote stakeholders' participation, while  
6 739 accompanying regional decision making. The knowledge of researchers and  
7 740 stakeholders were integrated in the early stages when building land-use GIS layers  
8 741 (S1). Globally, this strategy improved the connectivity between research and  
9 742 stakeholders for planning land-use (Turton et al., 2007). Although the sequences S1  
10 743 and S3 gathered success from a participatory point of view, the participatory  
11 744 planning sequence S2 progressed with difficulties.

12  
13  
14 745 The modelling approach implemented in S2 aimed to 'mainstream' (Smit and  
15 746 Wandel, 2006) biodiversity considerations within land-use decision making and to  
16 747 maintain a continuum of actions linking conservation science to implementation  
17 748 (Venter and Breen, 1998, Cowling, 2005). Although the conservation planning  
18 749 products (map of conservation priorities) were successfully developed, those  
19 750 objectives were far from being achieved. We analyse three possible explanations of  
20 751 this failure in the following paragraphs.

21  
22  
23 752 The modelling tool we used in S2. MARXAN is a rigid and complex tool. In  
24 753 addition, this tool embeds strong hypothesis about land-use management and  
25 754 conservation, such as, for instance, the attribution of a value to biodiversity features.  
26 755 The participants globally disagreed with this approach and thus rejected the tool.  
27 756 Paradoxically, they agreed with the map of conservation priorities produced using  
28 757 MARXAN.

29  
30  
31 758 The implementation of new conservation measure is not socially acceptable as a  
32 759 major proportion of the island territory (43%) is already protected within reserves  
33 760 (mainly the National Park). Concomitantly, basic societal needs such as housing and  
34 761 transport are not satisfied. This paradox creates tensions within the society and  
35 762 among stakeholders. The global perception is that conservationists already achieved  
36 763 their objectives through the creation of the National Park. Consequently, other  
37 764 stakeholders prevent the integration of conservationists in the land-use debate.

38  
39  
40 765 State institutions, including the DIREN and the National Forest Office have  
41 766 operated as exclusive representatives of the conservation sector within the land-use  
42 767 debate. In reality, the conservation sector is plural and heterogeneous, also  
43 768 composed of non-governmental organisations (National Botanical Garden, SREPEN,  
44 769 Vie Océane and Association Nature et Patrimoine among others) and individuals. In  
45 770 the sensitive context of the implementation of the National Park those institutions  
46 771 needed to control the conservation debate and this could explain why non-  
47 772 institutional conservationists (e.g. scientists for instance) were ousted from the SAR  
48 773 revision. This will probably change when the newly declared National Park will be  
49 774 firmly implemented, as its governance associates members from the civil society.

### 50 775 51 52 53 54 55 776 ***7.3. The researcher's posture in the participatory modelling process***

56 777 Analysing and questioning researcher's posture in a context of action research is  
57 778 central to understand their relationship to the participatory process and to the others  
58 779 participants. Here, we distinguish the researcher-organisers who led the participatory  
59 780 modelling process from the researcher-participants involved in it.

781 In S1 researcher-participants were initially perceived as neutral data providers by  
1 782 stakeholders external to the process. Nevertheless, some researchers left this  
2 783 methodological stance to justify the attribution of a conservation value to agricultural  
3 784 landscapes. This shift of posture created tension among researchers from G1 and  
4 785 G2 and stakeholders from the agricultural sector from G2.

6 786 In S2 the researchers-organisers soon embraced a conservationist posture  
7 787 stating that the implementation of complementary reserves in the lowlands was  
8 788 needed. This statement was based on a so-called objective knowledge of the  
9 789 increasing pressures on biodiversity. In fact, most conservation planning applications  
10 790 are based on such pre-determined statement and view the participatory process as a  
11 791 way to impose those statements to stakeholders. This partial stance is another  
12 792 possible explanation of the exclusion of biodiversity researchers from the SAR  
13 793 revision: in S3, “conservation-friendly” researchers would have aggravated tensions  
14 794 among stakeholders involved in the land-use debate.

15 795 The researchers-organisers in the S3 adopted the ComMod posture described in  
16 796 Bousquet et al. (1999). As neutrality is quite impossible in a participatory process,  
17 797 they tried to be as clearer as possible about their hypotheses; their stakes and their  
18 798 objectives. To this purpose, they involved stakeholders in the first steps of the  
19 799 building of the social-ecological model. The complexity of natural and social  
20 800 dynamics was shared with all participants of G2. The simplifications were recognized  
21 801 by all participants as necessary to achieve the common objectives: to create a model  
22 802 really useful for the SAR revision. The compromises were also made altogether. This  
23 803 open modelling process was time consuming but helpful to build a common vision of  
24 804 the structure and dynamics of the system represented in the model and its limits  
25 805 (Daré et al, 2008; Daré et al, 2006). This posture facilitated information and data  
26 806 transmission from researchers to stakeholders and vice versa. This posture  
27 807 reinforced the trust between G2 members, which was also helpful when the model  
28 808 created with G2 was modified with G3 members.

## 35 809

### 36 810 **8. General research implications and perspectives**

37 811 For many years, the issue of interactions between nature and society has been  
38 812 investigated by researchers from various study fields with their particular  
39 813 background, focus and methods. Thus, conservation planning has long been guided  
40 814 by the positivist paradigm in which humanity is viewed as an external threat to the  
41 815 internal equilibrium of a pre-extant nature. Opposed to this vision, we view the  
42 816 human-nature system as a whole evolving, heterogeneous and complex system of  
43 817 mutual interactions between society and nature (Holling, 1987, Gunderson and  
44 818 Holling, 2002, Folke et al., 2005).

45 819 More recently, nature and social science met in the holistic paradigm of  
46 820 constructivism (Piaget, 1967, see also Bourdieu, 1987). Constructivism relates to the  
47 821 idea of post-modernism, post-normal science (Funtowicz and Ravetz, 1991) and soft  
48 822 systems (Checkland and Scholes, 1990). Constructivism states that there is not an  
49 823 objective reality but that the reality is constructed by the individual based on its  
50 824 knowledge. In our study, we adopted this conceptual scheme to develop the  
51 825 participatory modelling sequences. This approach that recognises the existence and  
52 826 legitimacy of a diversity of points of view about the system management (here, land-  
53 827 use and biodiversity) need to be investigated by conservation planners (Bolte et al.,

828 2007). Although many conservationists embrace an ethical–moral approach,  
1 829 claiming that the right of nature to exist should be considered regardless of its  
2 830 contribution to society (Beatley, 1989), we considered them as legitimate  
3 831 stakeholders among others.

5 832 More practically, our study points out the limitations of the systematic  
6 833 conservation planning framework (Cowling at al., 2003, Knight et al., 2006). This  
7 834 framework is a reference for conservation planning applications worldwide. It  
8 835 involves a social and a biological assessment followed by a planning step and a  
9 836 stakeholders' involvement. The basic assumption is that the stakeholders will follow  
10 837 the conclusions derived from the planning. In practice the stakeholders' involvement  
11 838 rarely happens and the planning step is done by a narrow group of conservation  
12 839 experts who make strong assumptions about the territory. The focus is often made  
13 840 on strict ecological aspects and the social assessment is generally designed similarly  
14 841 to a biological assessment focusing mainly on mapping human activities in the  
15 842 landscape. Our study shows that conservation planning shouldn't be limited to a  
16 843 scientific modelling exercise disconnected from broader societal considerations. So-  
17 844 called *conservation planners* should rather engage within existing decision-making  
18 845 arenas and institutions to integrate biodiversity conservation into land-use planning.

23 846 Conservation planning applications are generally implemented using plug-and-  
24 847 play conservation software. Such normative tools (and affiliated conceptual  
25 848 frameworks) channel interactions with stakeholders and restrict them. For instance,  
26 849 in MARXAN (Ball and Possingham, 2000) all aspects of the conservation plan are  
27 850 reduced to costs. Such implicit assumptions often fail to reflect the non-monetary  
28 851 values of stakeholders. Consequently, stakeholders often end up very frustrated as  
29 852 most of their complex and specific issues do not fit in this framework. This is, in fact,  
30 853 inefficient as the conservation planning process is then rejected by stakeholders and  
31 854 not implemented. Participatory modelling is a way to avoid this failure by involving  
32 855 stakeholders earlier in the “modelling for planning” process so that they co-construct  
33 856 it.

37 857 More effort should be deployed to connect conservation planning processes with  
38 858 public spatial planning processes. Our study shows that this complexity can only be  
39 859 addressed through better integration of biodiversity conservation issues into  
40 860 mainstream land-use planning (Cowling, 2005). To this purpose, a combination of a  
41 861 systematic conservation planning approach with a participatory modelling approach  
42 862 is a research direction to investigate further. Future research should focus on a  
43 863 closer integration of spatial modelling tools (optimization and simulation), biodiversity  
44 864 mapping, scenario building and stakeholder integration.

47 865 Finally, we do not believe that models are the Holy Grail of spatial planning.  
48 866 They are, however, useful to support negotiations processes among stakeholders.  
49 867 Conservation planning is a component of land-use planning, not the converse. In this  
50 868 framework, a companion modelling approach would promote the integration of  
51 869 conservation into the land-use planning debate, thus contributing to develop and to  
52 870 maintain a research-implementation continuum that will promote integrated  
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## 15 889

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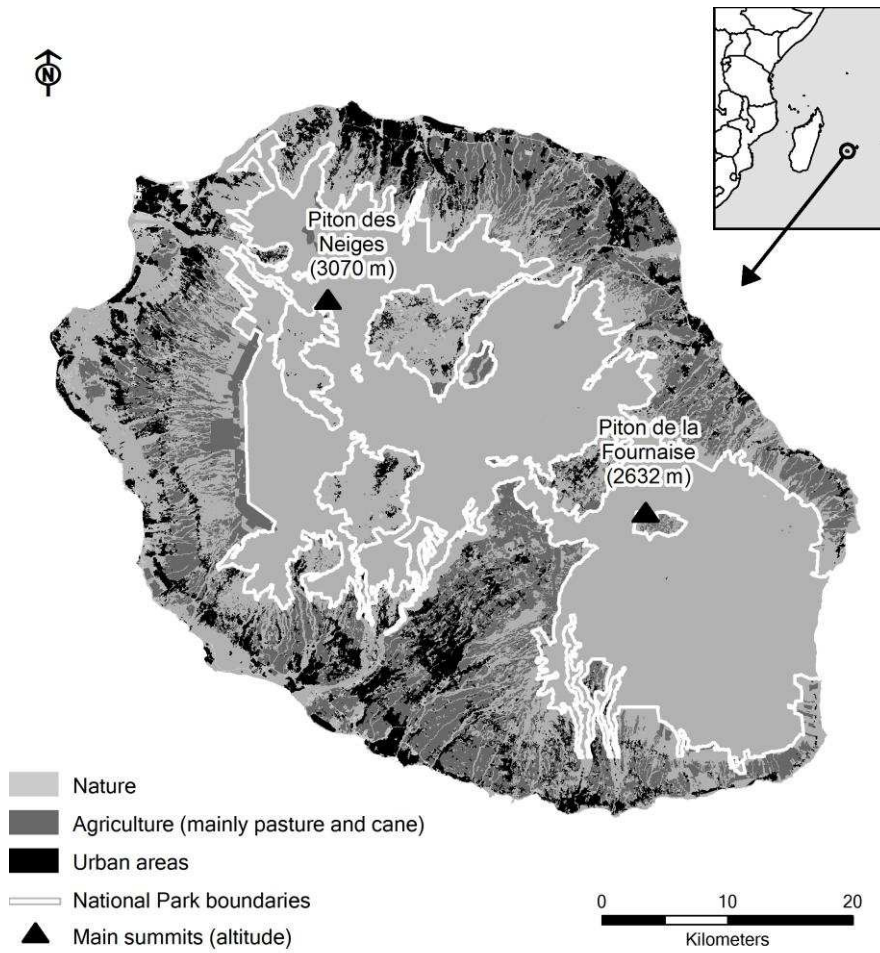
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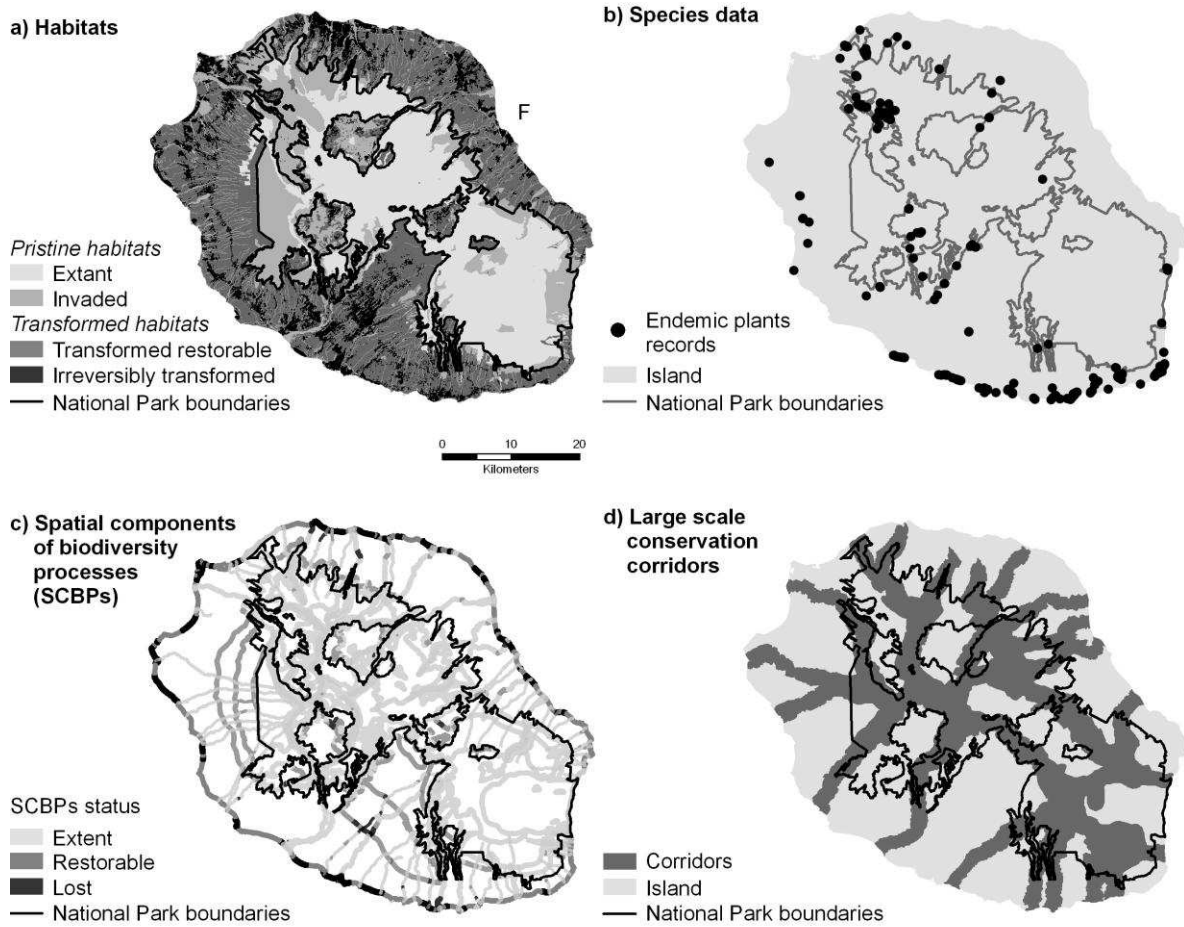
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**Figure 1:** Land-use map of Réunion Island (21°06' S 55°36' E). Urban and agricultural areas are currently expanding toward the uplands.



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**Figure 2:** Maps showing, a) the transformation status of habitats, b) record data on endemic plants (National Botanical Garden of Mascarin), c) the Spatial Components of Biodiversity Processes (SCBPs) and d) the large scale conservation corridors.



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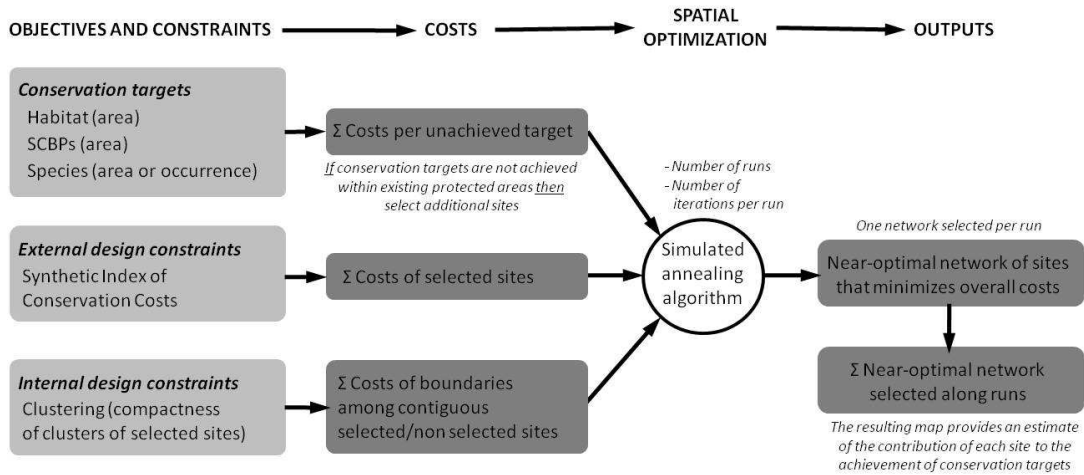
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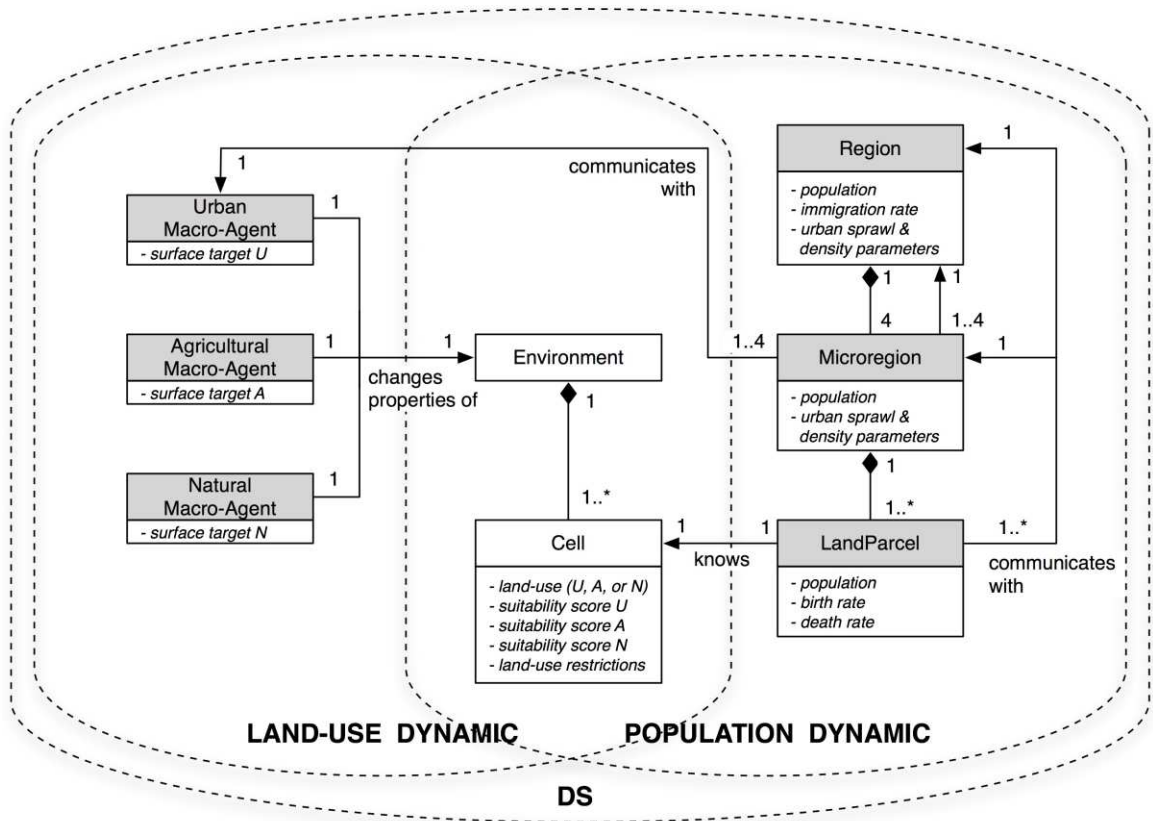
1102 **Figure 3:** The spatial optimization process embedded in MARXAN selects an  
 1103 optimal network of conservation sites that achieves conservation targets while  
 1104 minimising a set of costs. *External design constraints* are calculated for each  
 1105 planning unit (costly planning units are to be avoided). The calculation of the  
 1106 Synthetic Index of Conservation Costs is explained in Table 3. *Internal design*  
 1107 *constraints* are introduced to limit scattered spatial solutions by minimising the length  
 1108 of boundaries among selected and non selected planning units.  $\Sigma$  stands for *sum*.  
 1109 See Ball and Possingham (2000) for the model equations.



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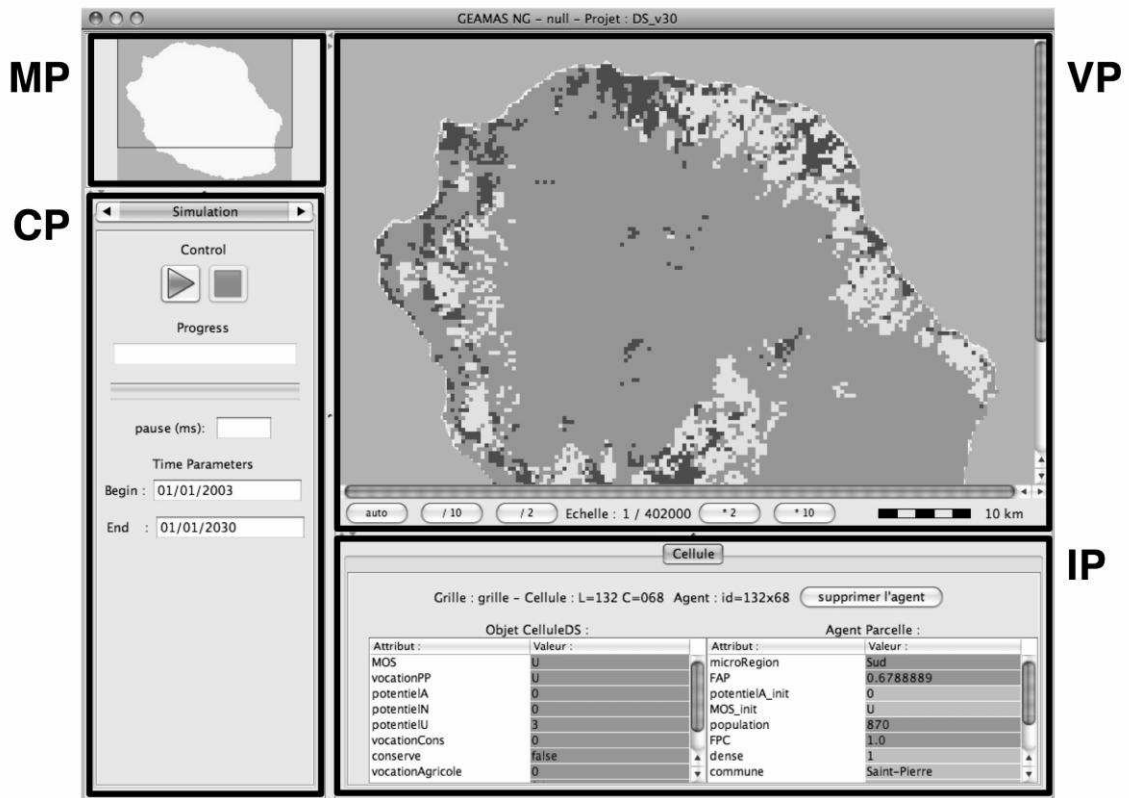
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**Figure 4:** UML class diagram of the land-use simulation model structure. Social entities are in grey while the white classes correspond to spatial entities.



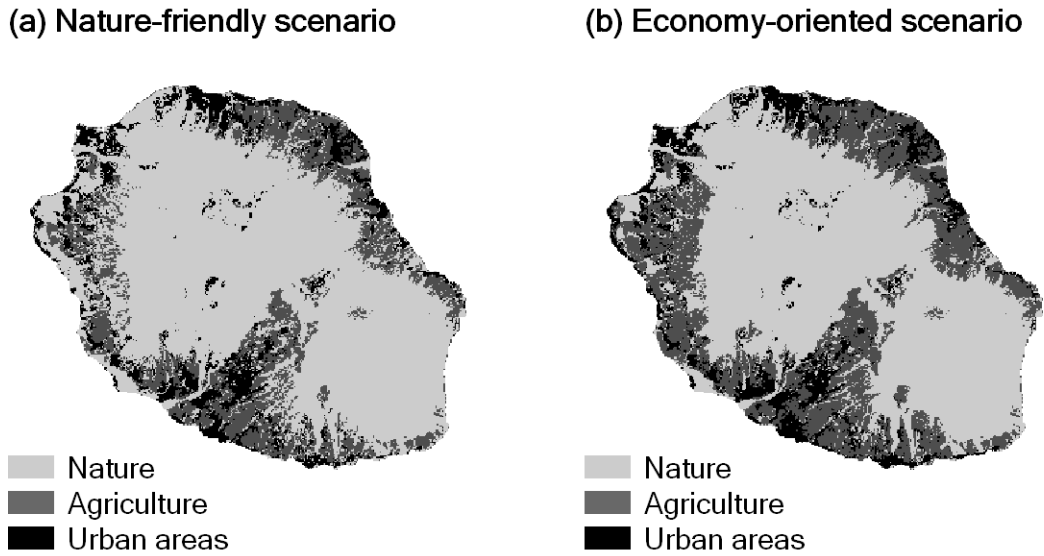
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**Figure 5:** The interface of the land-use simulation model is composed of 4 panels. The Minimap Panel (MP) enables to select and move the visible area of the island. The Control Panel (CP) enables to define simulations parameters, to initialise simulations, and to launch simulations. The View Panel (VP) displays the evolutions of the visible area via a colour graduation that shows the population or the land-use type of the cells. And the Information Panel (IP) displays the information about the system entities that can be selected by clicking on the VP. On the left side is the information on the selected *cell*, and on the right side is the information on the corresponding land parcel agents.

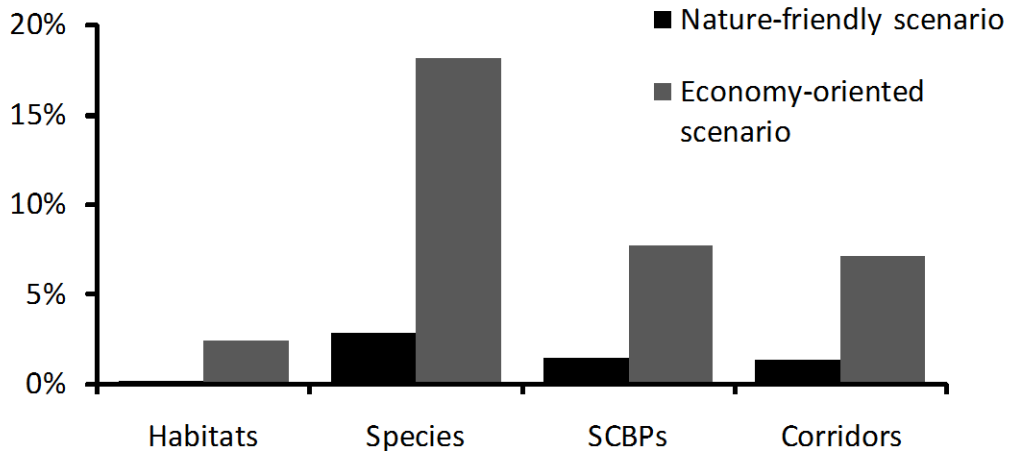


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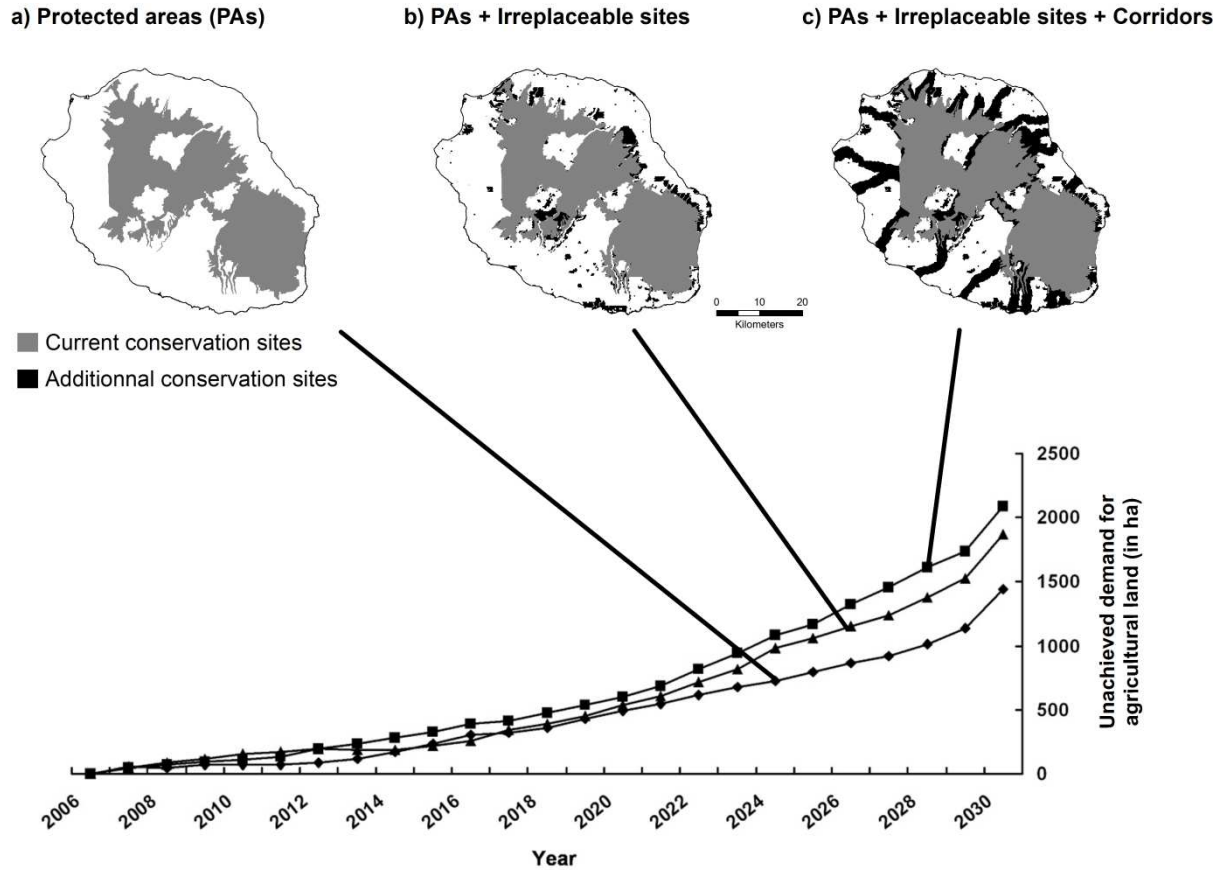
**Figure 6:** Land-use map obtained by simulation at the horizon 2030 with two of the scenarios simulated for the foresight process of the SAR: the *Nature-friendly* scenario (a), the *Economy-oriented* scenario (b) and their respective impacts on biodiversity features compared to an initial state in 2005 (c).



(c) Percentage of loss (surface or occurrence) per category of biodiversity feature per scenario (compared to 2005)



**Figure 7:** The impact of implementing additional reserves on the satisfaction of the agricultural demand for land (along the *Trend scenario*) with the current conservation reserve network only (a), when conserving the additional irreplaceable sites identified in the modelling sequence 2 (b) and when adding the large scale conservation corridors (c). The exponential shape of the curves is due to the concomitant conversion of agricultural land by urbanisation in the lowlands.



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Ecological habitat category grouped per altitude	Area before human colonization (km <sup>2</sup> )	Current area (km <sup>2</sup> )	Transformed (%)
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Wetlands	8	7	12
Subalpine	205	177	14
Mountain	564	400	29
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Coastal	14	3	78
Lowland	1165	115	90
<i>Total</i>	<i>2504</i>	<i>1008</i>	<i>60</i>

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Conservation of natural and agricultural patrimony and landscapes	2		
Rationalisation of urban sprawl	3	2	2
Social cohesion			3
Housing a million of inhabitant			1
Employment		3	
Steady development of the economy		1	

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Restoration cost	The restoration of transformed ecosystems involves massive investments in addition to other conservation costs. Restoration cost is low in <i>pristine</i> habitats and maximum in <i>irreversibly transformed</i> habitats.	0 - 10
Conversion pressure cost	Conversion pressure is the probability of habitat conversion by urbanisation, agriculture and invasive plants in each planning unit. This cost varies from 0 (null probability) to 10 (high probability).	0 - 10

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1168 **Table 4:** Description of the four land-use scenarios defined by the SAR revision  
 1 1169 participants and their transcription in the land-use simulation model.  
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Scenario	Motto	Main characteristics	Transcription in DS
Trend	The 'Let it be-island' <i>Inaction, weak organisation and socio-economic crisis</i>	Economy centred on the internal market Unachieved targets for housing and agriculture (socio-economic crisis) Uncontrolled urban sprawl on agricultural land and pristine habitats Protection of biodiversity in statutory reserves only. Increasing costs for the management of renewable resources.	Population still accumulating rather in the southern and western parts of the Island Low ratio of urban densification The agricultural sector targets a stable surface Only the current statutory reserve network is preserved
Nature-friendly	The 'Green island' <i>Attractive island</i>	Economy open to the external market thanks to its attraction for tourism Polarised densification of urban areas Protection of agricultural lands Protection of biodiversity in statutory reserves only	Population accumulating rather in the eastern and the northern part of the Island. Systematic high urban densification Agricultural areas are forbidden for urbanisation Only the current statutory reserve network is preserved
Economy-oriented	The 'competitive island' <i>Expansion of urbanisation and agriculture</i>	Economy centred on the internal market Polarised densification of urban areas Large expansion of agriculture on pristine habitats Protection of biodiversity in statutory reserves only.	Population still accumulating rather in the southern and western parts of the Island Systematic high urban densification The agricultural sector targets a 25% surface increase Agricultural areas are forbidden for urbanisation Only the current statutory reserve network is preserved
Urbanisation-oriented	The 'City-island', <i>Ravenous urbanisation and spatial compensations for agriculture</i>	Economy centred on the internal market Polarised urban densification and urban sprawl on agricultural lands and pristine habitats Protection of biodiversity in statutory reserves only	Population still accumulating rather in the southern and western parts of the Island Slightly higher densification rates The agricultural sector targets a 5% surface increase

Only the current statutory  
reserve network is  
preserved

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Figure 1  
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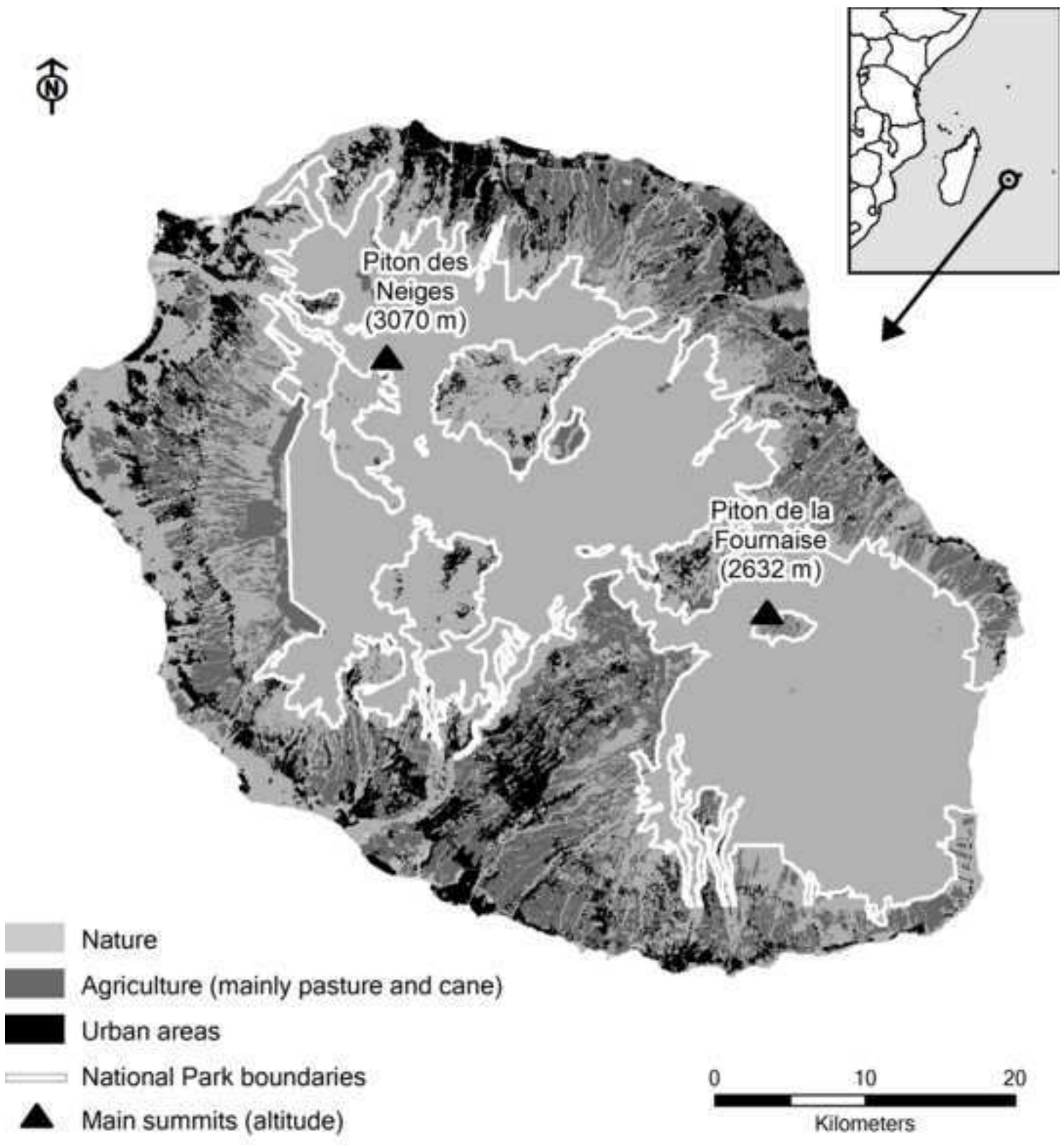
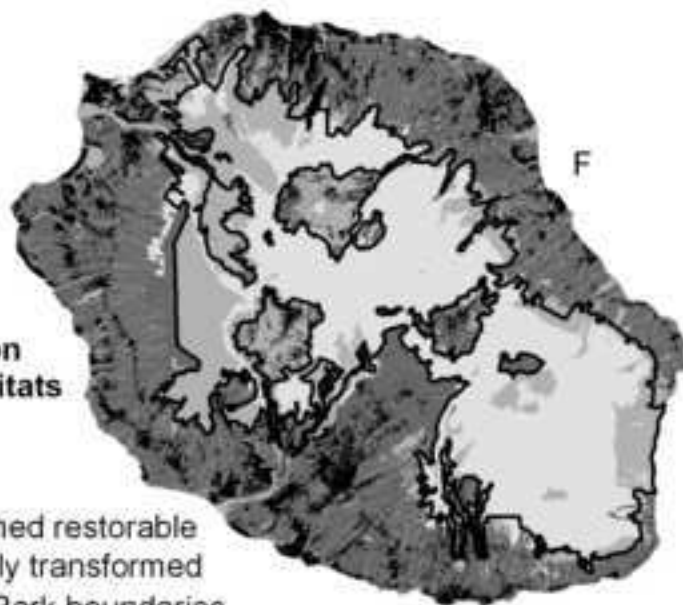


Figure 2  
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a) Habitats

Transformation status of habitats

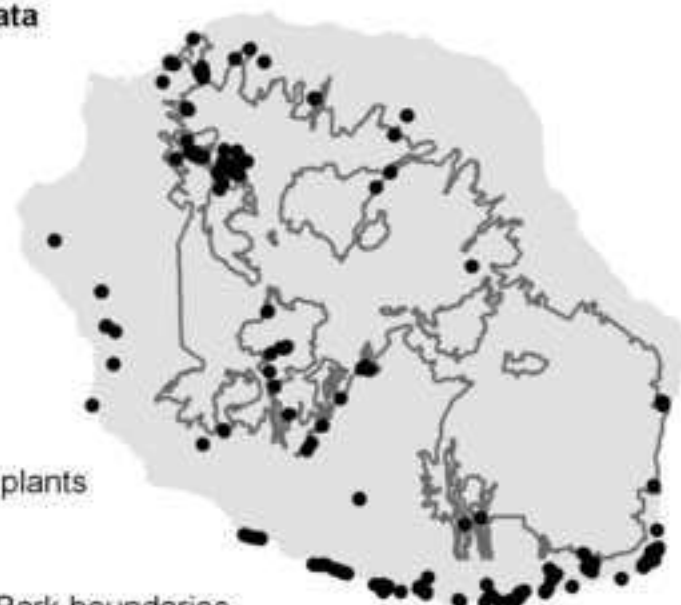
- Extant
- Invaded
- Transformed restorable
- Irreversibly transformed
- National Park boundaries



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Kilometers

b) Species data

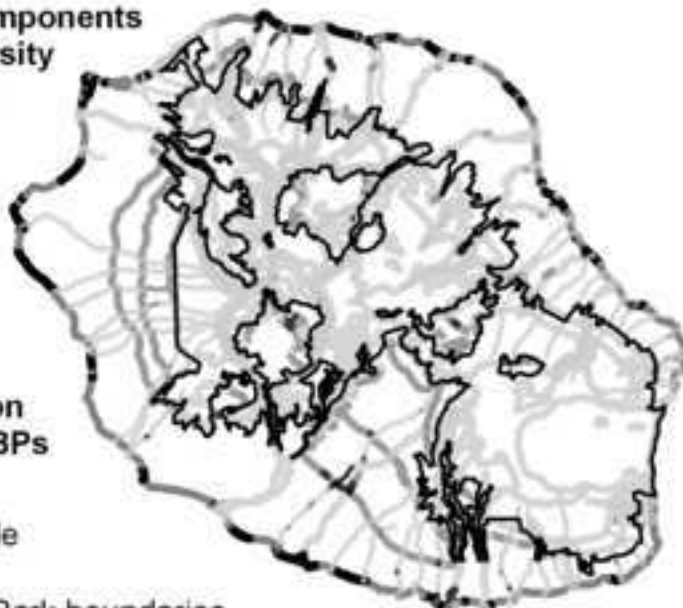
- Endemic plants records
- Island
- National Park boundaries



c) Spatial components of biodiversity processes (SCBPs)

Transformation status of SCBPs

- Extant
- Restorable
- Lost
- National Park boundaries



d) Large scale conservation corridors

- Corridors
- Island
- National Park boundaries

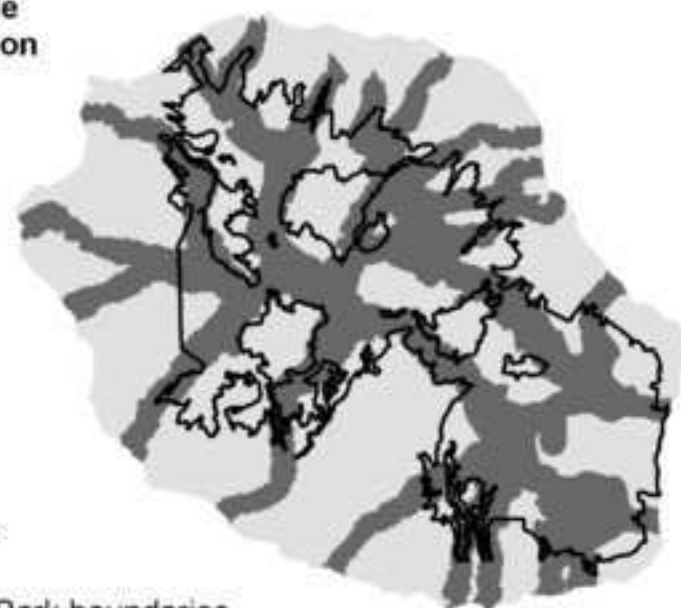


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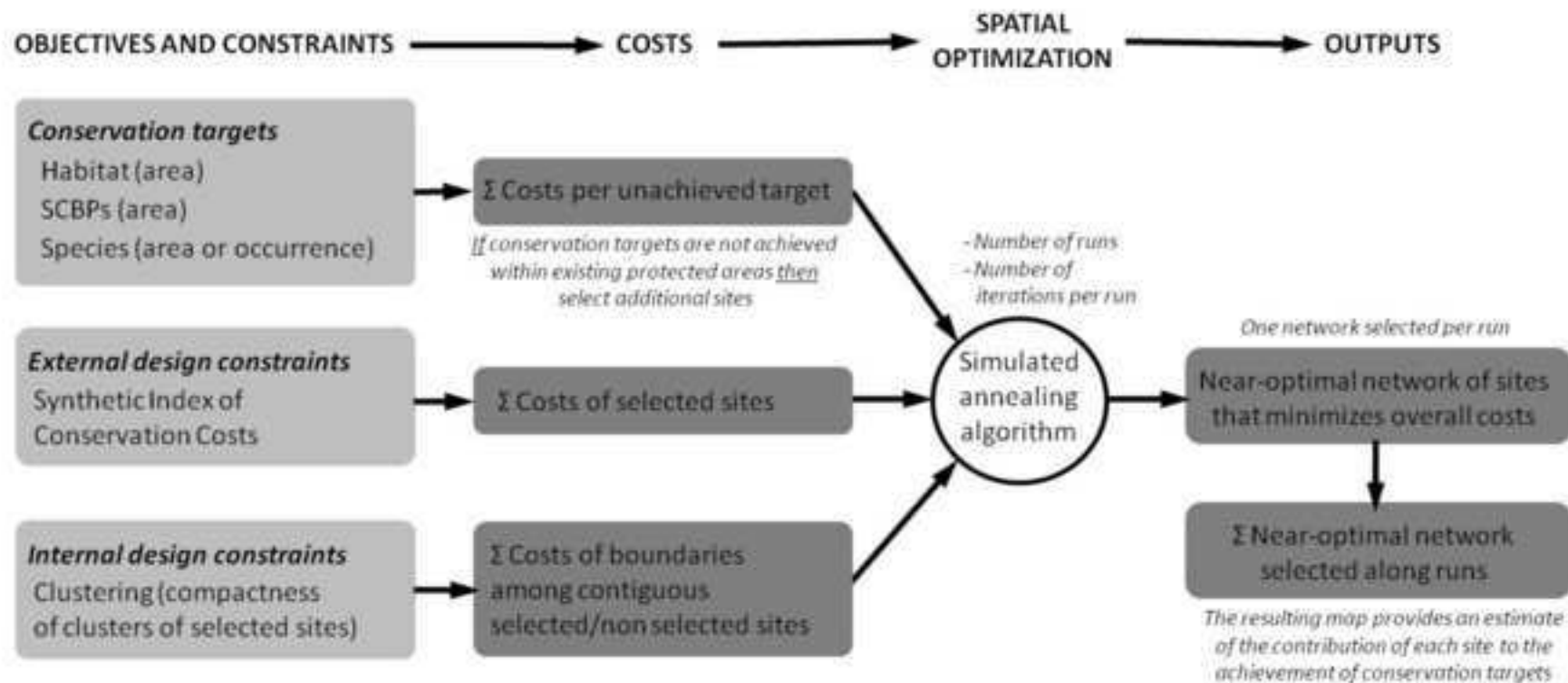


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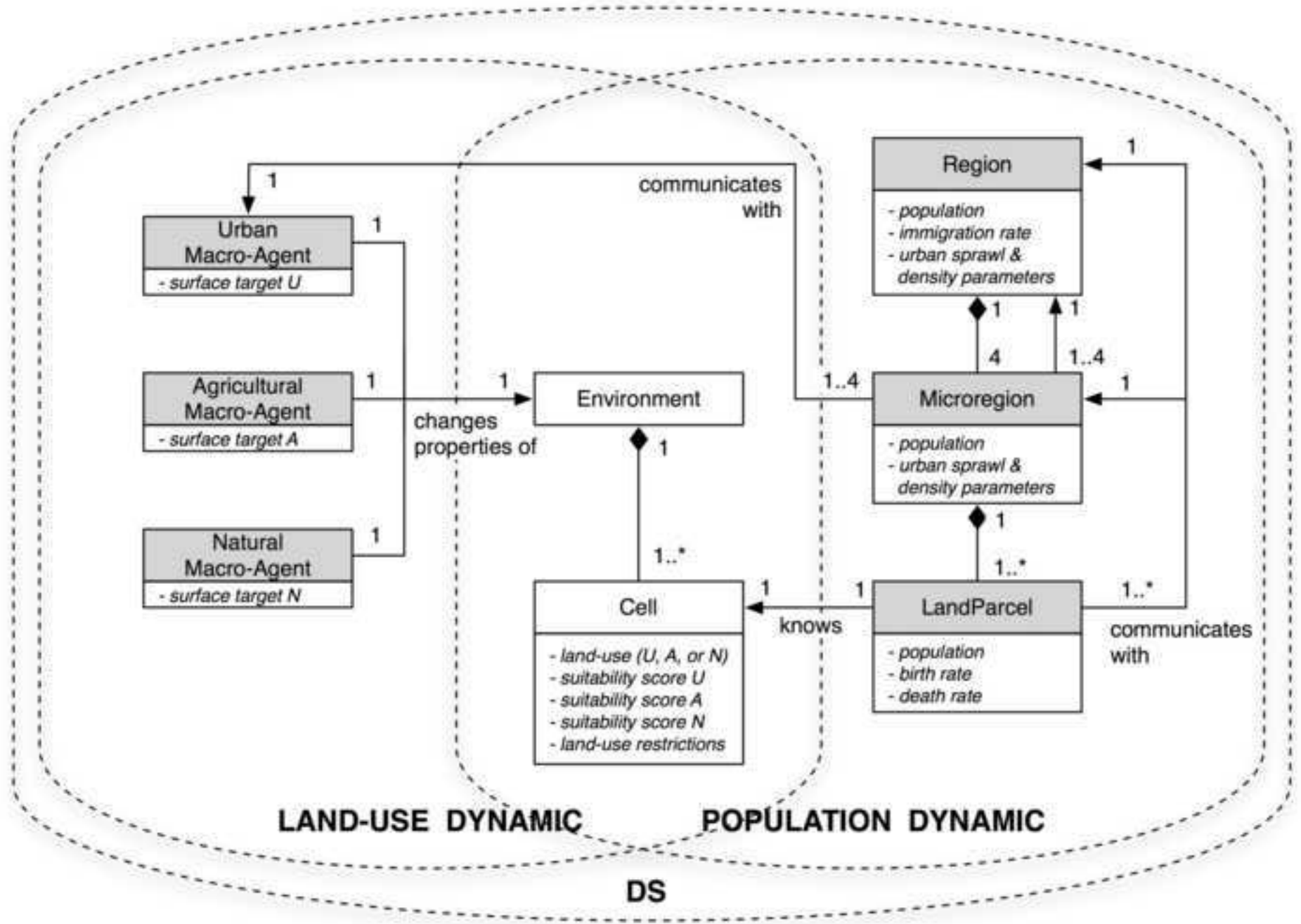
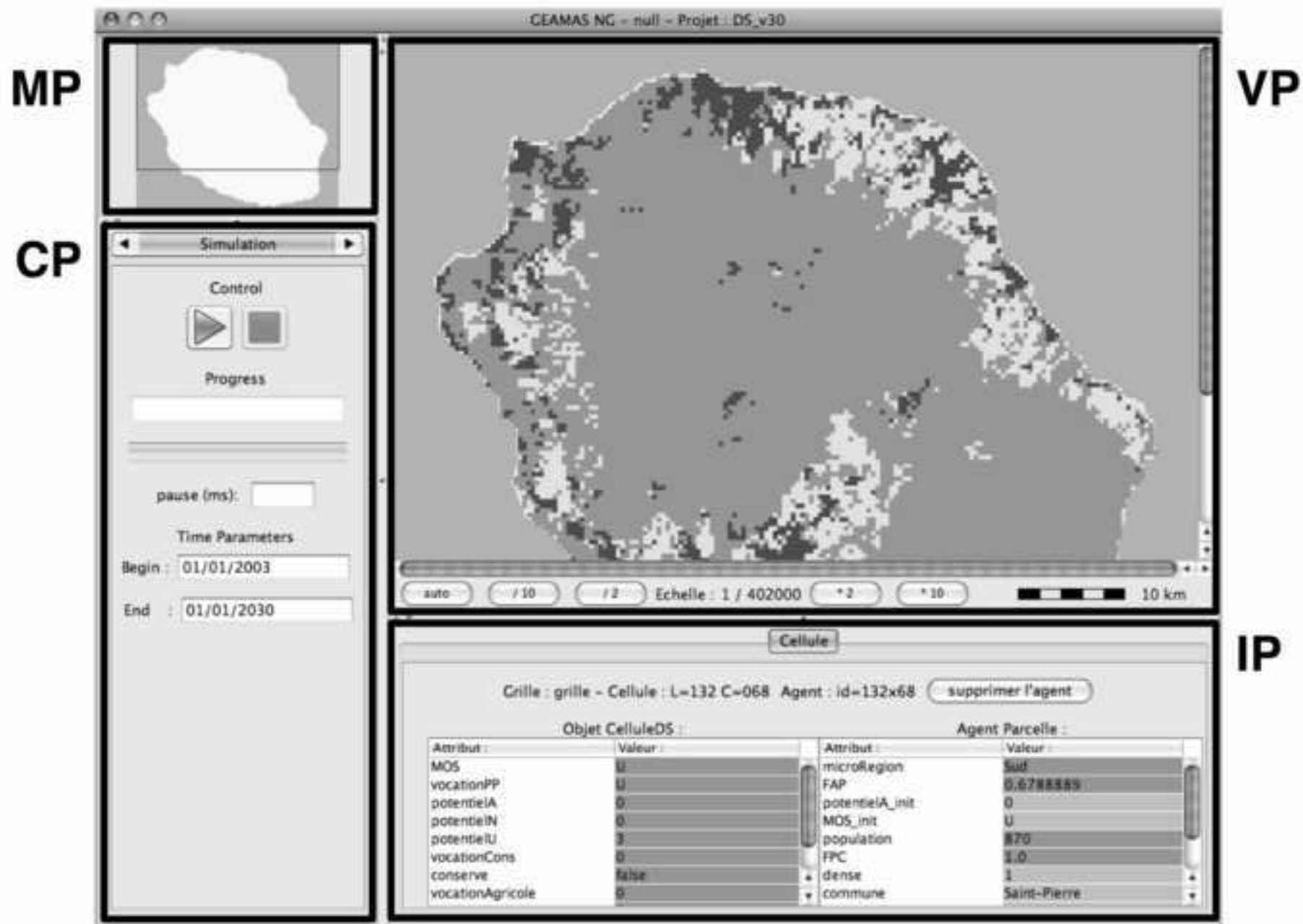
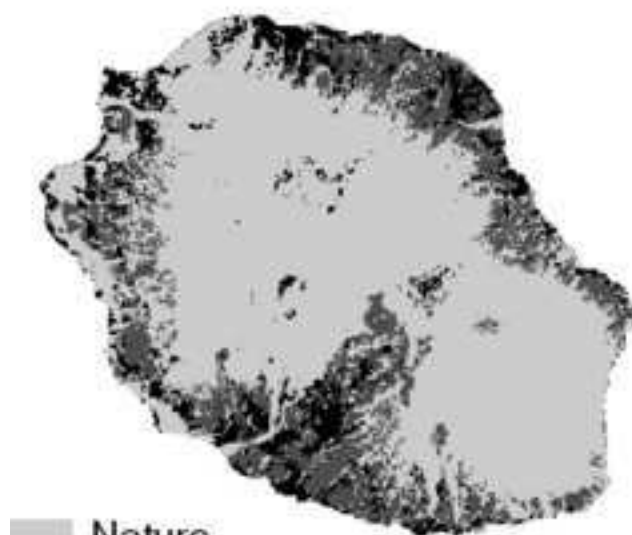


Figure 5  
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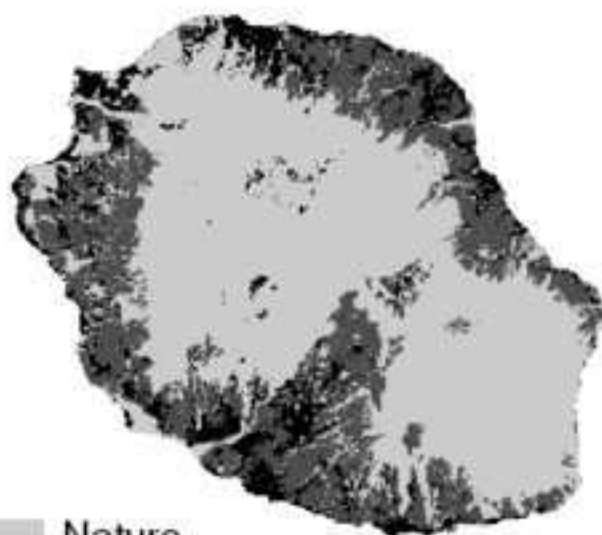


(a) Nature-friendly scenario



■ Nature  
■ Agriculture  
■ Urban areas

(b) Economy-oriented scenario



■ Nature  
■ Agriculture  
■ Urban areas

(c) Percentage of loss (surface or occurrence) per category of biodiversity feature per scenario (compared to 2005)

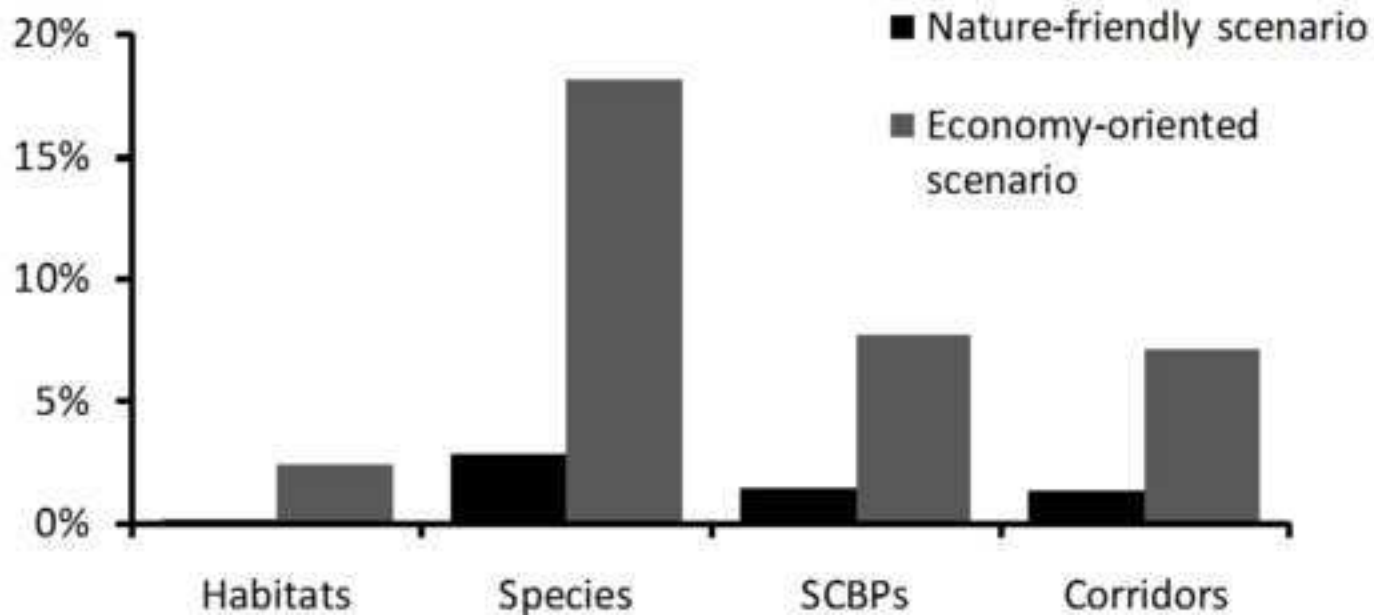
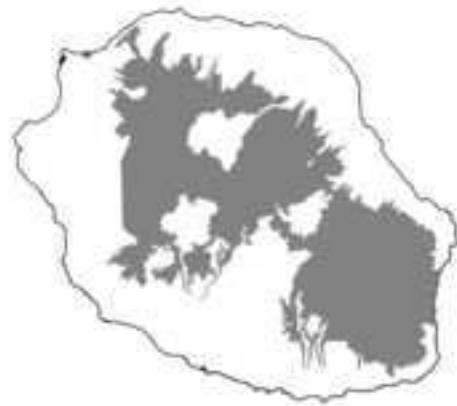


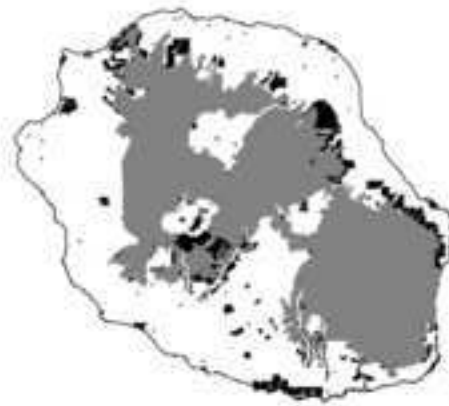


Figure 7  
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a) Protected areas (PAs)



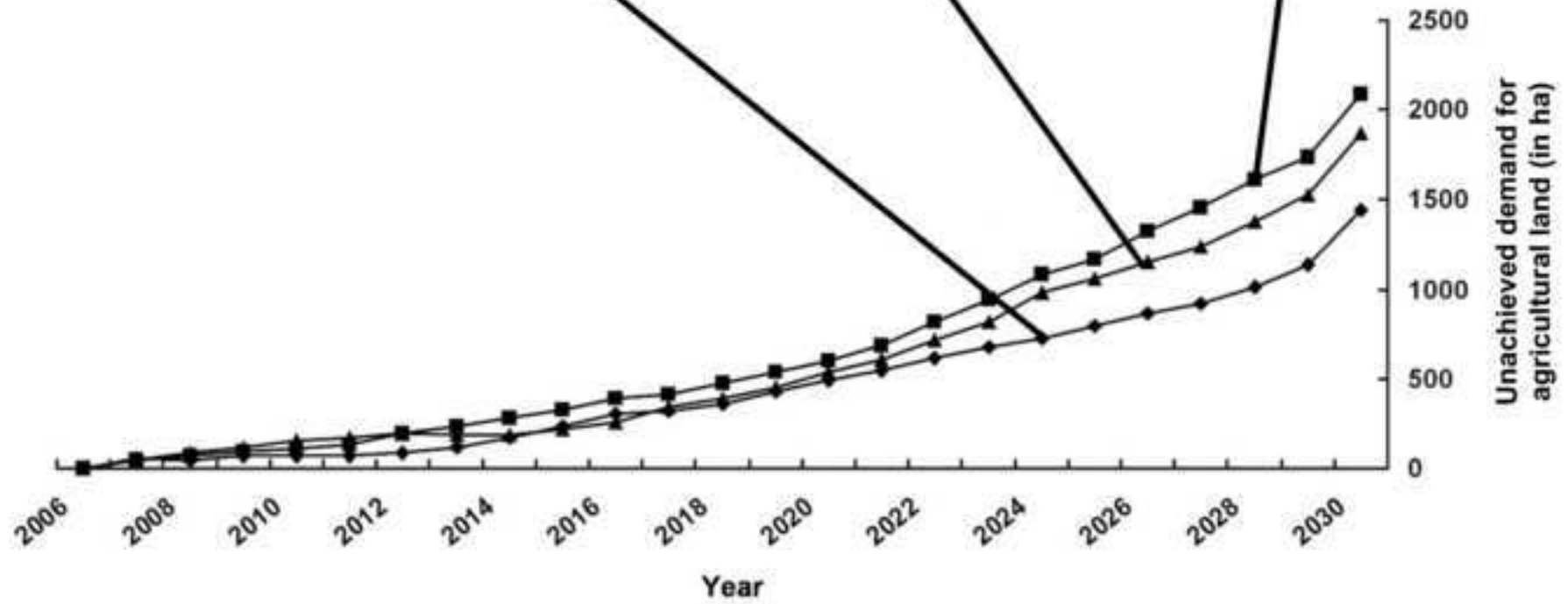
b) PAs + Irreplaceable sites



c) PAs + Irreplaceable sites + Corridors



■ Current conservation sites  
■ Additional conservation sites



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