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## Title page

# Understanding interlinkages between long-term Trajectory of Exposure and Vulnerability, path dependency and cascading impacts of disasters in Saint-Martin (Caribbean)

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## Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

1 **Understanding interlinkages between long-term Trajectory of Exposure and Vulnerability,**  
2 **path dependency and cascading impacts of disasters in Saint-Martin Island (Caribbean)**

3  
4 **Abstract**

5 This empirical and interdisciplinary study investigates the contribution of deeply enrooted social-  
6 political factors to the accumulation of exposure and vulnerability and amplification of cascading  
7 impacts of disasters, with implications on the creation and reinforcement of path dependency  
8 maintaining social-ecological systems on a maladaptive trajectory. Applying the Trajectory of  
9 Exposure and Vulnerability approach to Saint-Martin (Caribbean), we more specifically highlight  
10 how the causal chain linking historical geopolitical and political-institutional drivers to legal,  
11 economic, demographic, sociocultural, planning-related and environmental drivers, created the  
12 accumulation of exposure and vulnerability over time and contributed to the propagation and  
13 amplification of the impacts of tropical cyclones Irma and José in 2017. We find that historical  
14 social-political dynamics involving unsustainable development and settlement patterns, the  
15 weakness of local institutions, population mistrust in public authorities, high social inequalities  
16 and environmental degradation maintained Saint-Martin on a maladaptive trajectory through  
17 powerful reinforcing mechanisms operating both between and during cyclonic events. This study  
18 demonstrates that long-term interdisciplinary approaches are required for a better understanding  
19 of path dependency and the identification of levers to break it in risk-prone contexts. In Saint-  
20 Martin, breaking path dependency requires the alignment of local institutional capacities with  
21 national risk reduction policies, the promotion of social justice and involvement of local  
22 communities in decision making. This study therefore confirms the relevance of backward-  
23 looking approaches to support forward-looking climate adaptation.

26 **Keywords**

27 Small islands, social-ecological systems, climate disasters, cascading effects, path dependencies,  
28 adaptation.

29

30 **1. Introduction**

31 Since the early 2010s, the need for a better understanding of the multi-decadal to multi-centennial  
32 human processes shaping the exposure, vulnerability and adaptive capacity of contemporary  
33 societies to climate-related hazards has been increasingly recognized (Adamson *et al.*, 2018;  
34 Cardonna *et al.*, 2012; Dilling *et al.*, 2015; Douglass & Cooper, 2020; Fawcett *et al.*, 2017;  
35 Jurgilevich *et al.*, 2017). These processes have their roots in historical, political-institutional,  
36 social, legal, economic and environmental settings and local challenges, including endogenous  
37 (e.g. community cohesion, memory and knowledge transmission, individual support to collective  
38 action) and exogenous (e.g. role of migrations, transnational finance, international relations)  
39 resources and drivers (Nunn, 2007; Barnett & Waters, 2016; Holdschlag & Ratter, 2015, 2016;  
40 Lauer *et al.*, 2013; McLeman, 2010; Pelling & Uito, 2001; Schwartz *et al.*, 2011).

41 Better understanding the long-term processes that shape exposure, vulnerability and adaptation  
42 (see Box 1 for definitions) locally can help to promote risk reduction and climate adaptation for  
43 three interrelated reasons. First, because such an approach is key to comprehending the root  
44 causes of exposure and vulnerability that are not immediately evident because they are embedded  
45 within historical factors and complex interactions between the multiple components of social-  
46 ecological systems. Root cause analysis thus reveals how the conditions of risk emerged,  
47 persisted and accumulated over time (Barclay *et al.*, 2019; Bordner *et al.*, 2020; De Scally, 2014;  
48 Fraser *et al.*, 2016; Lichtveld, 2017; Schultz *et al.*, 2018; Spennemann, 1996). Second, this in  
49 turn allows one to understand the complex and escalating cascading effects generated by climate-  
50 related events, the impacts of which are generally disproportionate to the magnitude of the

51 triggering event (Alexander, 2018; Alexander & Pescaroli, 2019; Felsenstein *et al.*, 2020; Menoni  
52 & Boni, 2020; Pescaroli & Alexander, 2015). Third, analyzing the long-term processes enrooted  
53 in societies' history makes it possible to capture path dependencies that may hinder the  
54 implementation and/or effectiveness of actions taken to reduce risk and promote adaptation to  
55 climate change (Duvat *et al.*, 2017a; Duvat *et al.*, 2020; Parsons *et al.*, 2019; Wise *et al.*, 2014).  
56 Path dependencies mean that antecedent pathways have a major influence in driving the current  
57 and future status of the system (Fawcett *et al.*, 2017; Pierson, 2000; Parsons *et al.*, 2019;  
58 Rasmussen *et al.*, 2009; Wise *et al.*, 2014). They set into motion political-institutional patterns  
59 that have generated prevailing rules and norms, power relations, values and knowledge cultures  
60 (Jeffers, 2014) that persist over time (due to system inertia) and are interconnected across space  
61 as a result of globalization and climate change (Alexander & Pescaroli, 2019; Fraser *et al.*, 2020;  
62 Hilhorst & Bankoff, 2004; Parsons *et al.*, 2019; Wise *et al.*, 2014).

63 To understand the interlinkages between long-term risk accumulation, path dependency and  
64 cascading effects of disasters, it is crucial to consider self-reinforcing mechanisms that both  
65 'reinforce the possibility that further steps will be taken along the same path thereby reinforcing  
66 past decisions' (Parsons *et al.*, 2019, p. 96) and amplify the impacts of triggering events when an  
67 'escalating point' is reached (Alexander, 2018). Self-reinforcing mechanisms operate both during  
68 and between (especially over the recovery and reconstruction phases) triggering climate events,  
69 and are highly influenced by interactions between local and higher level institutions (Felsenstein  
70 *et al.*, 2020; Fraser *et al.*, 2020; Parsons *et al.*, 2019; PEARL, 2018; Wise *et al.*, 2014). In this  
71 field of research, cross-disciplinary perspectives are particularly relevant because they are well-  
72 suited to interrogate interdependencies between both the different components of the considered  
73 system and this system and higher-level systems (Felsenstein *et al.*, 2020; Fraser *et al.*, 2020;  
74 Pescaroli *et al.*, 2018; Walters, 2012).

75 Only a limited number of studies (e.g. Fraser *et al.*, 2020; PEARL, 2018; Parsons *et al.*, 2019)  
76 used a long-term oriented approach to investigate on empirical bases the contribution of deeply  
77 enrooted processes to recent disasters and path dependency. In line with this emerging body of  
78 literature, we argue that reconstructing long-term Trajectories of Exposure and Vulnerability  
79 (TEV) can assist in identifying the factors that contribute to, and potential ways to overcome path  
80 dependency, in the context of disaster risk reduction and adaptation to climate change. Drawing  
81 on an interdisciplinary approach involving quantitative and qualitative methodologies, we  
82 analyze the long-term TEV of Saint-Martin (French side of the binational island of Saint-  
83 Martin/Sint Maarten, Caribbean region; Fig. 1) to tropical cyclones (TCs). We more specifically  
84 address three interrelated questions: (1) What are the key drivers that have shaped the TEV of  
85 Saint-Martin from the colonization in the seventeenth century to the Present? (2) How have these  
86 drivers interacted and caused vulnerability and exposure accumulation over time? (3) To what  
87 extent have such deeply enrooted mechanisms contributed to amplify the impacts of the 2017  
88 TCs and to create path dependency? To answer these questions, Section 2 introduces the case  
89 study context and methodology. Section 3 analyzes the drivers that have shaped the TEV of  
90 Saint-Martin over the last three centuries, as well as their interlinkages. Section 4 presents the  
91 cascading effects through which these drivers have amplified the impacts of the 2017 TCs.  
92 Section 5 discusses how a long-term TEV approach can promote a better understanding of and  
93 help breaking path dependency in risk-prone contexts.

94 **Box 1.** Terms used in this study.

**Cascading effects/impacts:** Situation where an initial factor or failure in a social-ecological system generates a sequence of escalating impacts propagating across sub-systems and resulting in the systemic disruption of the system (Pescaroli & Alexander, 2015)

**Causal chain:** Interdependencies between the various components of a social-ecological system that drive the accumulation of vulnerability and exposure over time in this system

**Driver:** Any natural or human-induced factor that directly or indirectly causes a change in a system (IPCC, 2019)

**Escalation point:** Critical juncture in cascades at which the interaction of vulnerabilities

and the concatenation of influences lead to a bigger impact than mere reaction to the primary factor/failure would suggest (Alexander, 2018)

**Exposure:** Presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected (IPCC, 2019)

**Path dependency:** ‘Historical sequences of connected and contingent events that set into motion institutional patterns that are linked over time and space’ (Parsons *et al.*, 2019, p. 96)

**Reinforcing effects/mechanisms:** Positive feedback loops that contribute to the accumulation of vulnerability and exposure within a system over time (Pescaroli & Alexander, 2015; Thomas *et al.*, 2020), and cause path dependency by reinforcing ‘the possibility that further steps will be taken along the same path’ (Parsons *et al.*, 2019, p. 96)

**Risk:** Potential for adverse consequences for human or ecological systems (IPCC, 2019)

**Saint-Martin :** refers to the French side of the island

**Sint Maarten:** refers to the Dutch side of the island

**Trajectory of Exposure and Vulnerability:** ‘Storyline of driving factors and processes that have influenced past to present territorial system exposure and vulnerability to impacts associated with climate variability and change’ (Duvat *et al.*, 2017a, p. 3)

**Vulnerability:** Propensity or predisposition to be adversely affected [and] encompasses [...] sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2019)

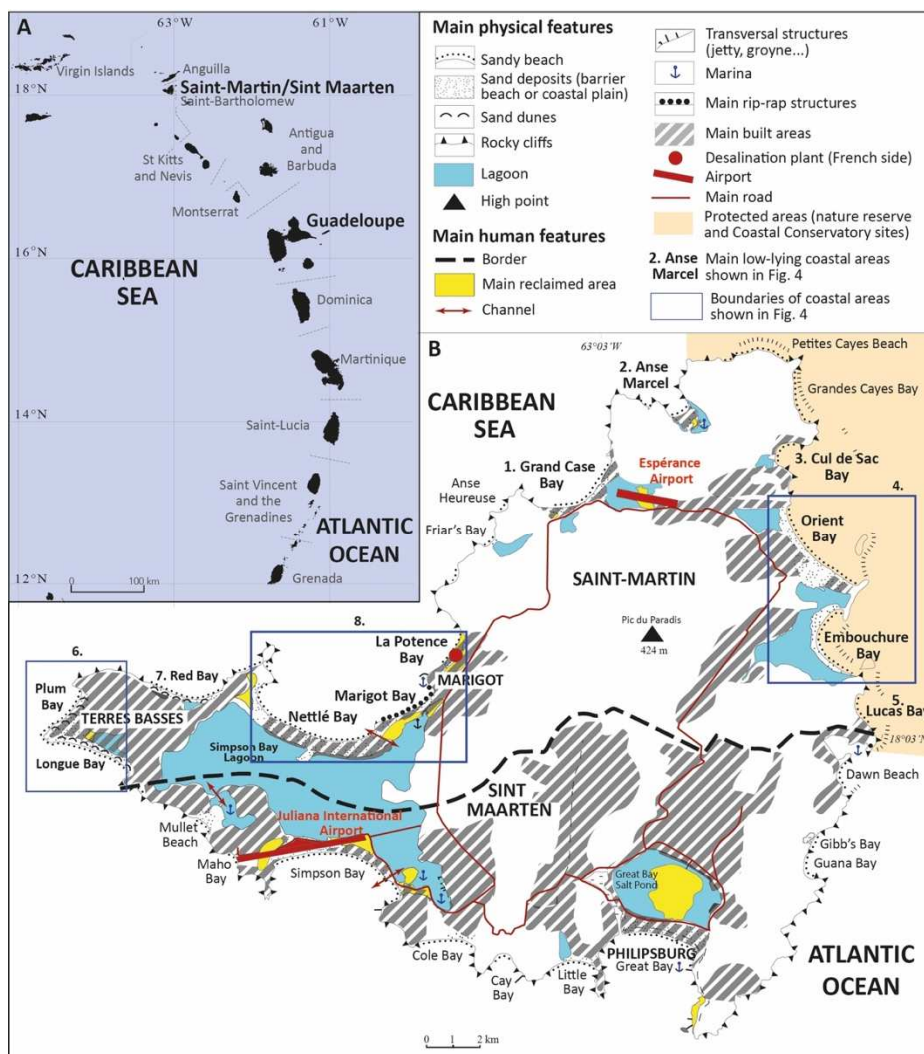
95

## 96 **2. Context of the study**

### 97 **2.1. Study area**

98 The French/Dutch island of Saint-Martin/Sint Maarten (90 km<sup>2</sup>) is situated at the northern end of  
99 the Lesser Antilles Arc (Fig. 1). It is a mountainous island, which exhibits steep slopes  
100 contrasting with low-lying coastal plains and 25 to 400 m-wide barrier beaches bordered by  
101 lagoons, some of which have mangrove forests. Elevations are <5 m on 25% of the island’s land  
102 area (DDE Guadeloupe, 2005), with beaches and barrier beaches being very low-lying and rarely  
103 bordered by sand dunes. Fringing reefs are restricted to the northeast, making most beaches  
104 highly exposed to cyclonic waves. During the Boreal summer, Saint-Martin is exposed to tropical  
105 depressions forming in the Cape Verde area and tracking to the west-north-west to reach the  
106 Caribbean islands. On average, twelve tropical depressions reach the latter per year, six of which  
107 reach the cyclone stage (Météo-France, 2005). The island has been severely affected by five

108 intense TCs since 1960, including Donna on 15 September 1960, Luis on 15 September 1995,  
 109 Lenny on 18 November 1999, and Irma (6 September) and José (9 September) in 2017. Irma was  
 110 the most intense of these TCs, with sustainable wind speed values of around 296 km/h and  
 111 significant wave heights reaching 9 m along the eastern coast (Duvat *et al.*, 2019). While Luis  
 112 was the first TC to cause extensive damage in coastal areas, Irma was by far the most devastating  
 113 TC that has affected Saint-Martin to date: 95% of buildings were damaged (Gustin, 2017) and the  
 114 total damage was estimated at 1.2 MM € (Desarthe *et al.*, 2020).



115  
 116 Fig. 1. Study area.  
 117 Panel A shows the location of Saint-Martin/Sint Maarten in the Caribbean region. Panel B highlights the  
 118 main physical and human features of the island, and the concentration of most built areas and critical



119 *infrastructure in the coastal zone in Saint-Martin. It also shows the location of urbanized and developed*  
120 *beach sites that are presented in Figs. 3 and 4.*

121  
122 The island has 78,000 inhabitants, 48% of whom live in Saint-Martin (54 km<sup>2</sup>, 637  
123 inhabitants/km<sup>2</sup>) and 52% in Sint Maarten (36 km<sup>2</sup>, 674 inhabitants/km<sup>2</sup>) (IEDOM, 2019). Most  
124 of Saint-Martin's population live in low-lying coastal areas and are employed in the tertiary  
125 sector. The latter provided 81.8% of jobs in 2016, most of which were directly or indirectly  
126 related to tourism, with tourist accommodation and catering, trade, other commercial services and  
127 the construction sector representing respectively 26.1%, 20.7%, 33.9% and 6.6% of jobs  
128 (IEDOM, 2019). The limited development of the agricultural (0.2% of jobs) and industrial (4% of  
129 jobs) sectors, due to limited potential, has caused high dependency on imports, even for staple  
130 goods. The island hosts > 2,400,000 tourists yearly (IEDOM, 2019), most of whom are North-  
131 Americans. Seventy-eight percent of tourists are cruise visitors landing at Philipsburg (capital of  
132 Sint Maarten), while the remaining 22% come in by plane, generally landing at Juliana  
133 International Airport, Sint Maarten (opened in 1944), as Saint-Martin only has (since 1972) a  
134 small airport receiving a limited number of international flights passing Guadeloupe before  
135 landing in Saint-Martin. Tourists arriving by plane stay in beachside hotels, villas and residences.  
136 Due to its advantageous tax exemption regime, Sint Maarten captures most of the tourists visiting  
137 the island. For a variety of reasons (especially lower competitiveness compared to Sint Maarten,  
138 exponential tourism growth artificially supported by tax exemption, severe cyclone-induced  
139 damage in the 1990s), Saint-Martin has faced chronic economic recession since the mid-1990s  
140 and therefore exhibits a high unemployment rate of 34.2%, against 8.9% in Sint Maarten  
141 (IEDOM, 2019). In 2018, the GDP per inhabitant was of 16,572€ and 22,529€ in Saint-Martin  
142 and Sint Maarten, respectively. In 2016, 61% of Saint-Martin's residents declared less than  
143 10,000\$ of yearly income, against 49.1% in Guadeloupe and 22.9% in mainland France.

144 Moreover, a ‘very high [but unknown] proportion of the economic activity of Saint-Martin is  
145 informal due to the dissimulation of economic activities and/or employees’ (IEDOM, 2019, p. 3).  
146 Since 2007, Saint-Martin is a ‘Collectivité d’Outre-Mer’ (COM) endowed with administrative  
147 autonomy. It has wide competences to regulate areas listed in the *General Local Authorities Code*  
148 (article LO6314-3), such as taxation, road transport, ports, highways, land owned by Saint-  
149 Martin, tourism, access of foreigners to employment, creation and organization of local public  
150 services and, since 2012, town and country planning, construction, housing and energy. Saint-  
151 Martin COM can also intervene in the environmental field by proposing local adaptations of the  
152 national environmental code, which then require the approval of the French State.

## 153 **2.2. Approach and Methods**

154 This study was conducted by a multidisciplinary team composed of social (historians, lawyers,  
155 human geographers) and physical (geomorphologists) scientists, supported by research engineers  
156 with expertise in statistics, Geographic Information Systems (GIS) and remote sensing  
157 techniques. This team performed documentary search and analysis using three points of entry,  
158 including (1) natural hazards, risks, disasters; (2) economic development, tax system; and (3)  
159 town and country planning, risk management, environmental management. Using these points of  
160 entry, team members identified relevant documents and databases in their field of expertise (see  
161 SM1 for details), including:

162 1. Historical archives from mainland France, Guadeloupe and Saint-Martin, which provided  
163 information on Saint-Martin’s political-institutional, tax, economic and societal history, as well  
164 as on the consequences of extreme climate events on this territory. This qualitative data also  
165 allowed us to understand the geopolitical context and relations of Saint-Martin with mainland  
166 France, Sint Maarten, Caribbean countries and the USA.

167 2. Legal texts obtained from the online public service *Légifrance* for State law and from the  
168 website of Saint-Martin COM for local law, which enlightened (i) various levels of legal  
169 intervention over time (by the French State, Saint-Martin as a municipality of Guadeloupe and as  
170 a COM), (ii) the content and evolution of law in different areas influencing coastal risks,  
171 including risk prevention, town and country planning, environmental and tax law. The analysis of  
172 law allowed us to detect changes occurring in these various fields since the decolonization in  
173 1946.

174 3. Public databases providing data on demography, society, economy, as well as numerical  
175 datasets produced by the French National Institute of Geographic and Forest Information (IGN),  
176 including high resolution elevation data, data related to the spatial distribution of buildings and  
177 roads, black and white aerial photographs (1947, 1969, 1984, 1989 and 1999 series), Web Map  
178 Service (WMS) with 1950-1965 aerial photographs and 2017 satellite imagery.

179 4. Scientific literature dating back to the 1960s, including in particular PhD theses on Guadeloupe  
180 and Saint-Martin.

181 5. Official reports produced by the French Senate since the 1990s. By providing detailed  
182 descriptions of the situation (sociocultural, economic, demographic, legal and institutional) of  
183 Saint-Martin at the time of senators' visits, these reports allowed us to capture context-  
184 specificities and to retrace the evolution of the situation of Saint-Martin over time. They also  
185 provided material on the French State policy designed to remedy the multiple problems faced by  
186 Saint-Martin (especially insecurity, unemployment and poverty, and political instability) and the  
187 success or failure of the measures implemented locally. These reports also helped us to  
188 understand the impacts of and responses to past TCs (especially Luis, 1995) and thereby  
189 contributed to overcome the main gap we faced in the document search phase, that is, the absence  
190 of any public report or communication on the management of past cyclonic crises.

191 In addition, we conducted fieldwork in November 2005; February-March 2007; October-  
192 November 2017; March, May, July and October-November 2018; and March 2019. The 2005-  
193 2007 field observations allowed us to characterize coastal development, coastal risk reduction  
194 measures (dominated by hard protection), town and country planning, environmental policies and  
195 coastal ecosystem condition. The post-cyclone field trips conducted over the 2017-2019 period  
196 enabled the analysis of Disaster Risk Reduction (DRR) policies and the in-depth analysis of 2017  
197 TCs' impacts and crisis management by the public authorities and inhabitants. DRR policies and  
198 crisis management were investigated through semi-structured interviews with public officers  
199 (national and local civil servants based in Saint-Martin and Guadeloupe in charge of risk,  
200 environmental, and town and country planning matters), the police force, the prosecutor of Saint-  
201 Martin's tribunal, and inhabitants living in severely damaged coastal areas. Officials were  
202 interviewed about (i) their responsibilities, own observations and understanding of the situation  
203 of Saint-Martin; (ii) how they managed failure in law implementation; (iii) the human and  
204 material resources available to fulfil their responsibilities; (iv) post-cyclone crisis management  
205 from the phase of increased vigilance until one month after the TCs; (v) the most severely  
206 affected areas; and (vi) the changes that they estimated to be desirable to reduce exposure and  
207 vulnerability to climate-related hazards in Saint-Martin (SM2 Tables 1A and 1B). The  
208 information collected among these actors was consistent. In addition, one hundred and two  
209 inhabitants living in different coastal areas were surveyed about their experience of TC Irma,  
210 using a before/during/after interview sequencing (SM2 Table 2). Interviewed inhabitants were  
211 met spontaneously on the ground and were voluntary to share their personal experience of the  
212 TCs. The interviews were conducted in public places not to be intrusive. The narratives of  
213 respondents were firstly analyzed individually, and the main common traits between them were  
214 secondly drawn. These narratives formed a coherent whole.

215 Data sharing (over the search phase) and analysis involved the setting up of a common ‘TEV  
216 database’. The latter took the form of a shared table comprising nine columns aimed at gathering,  
217 in chronological order and from 1648 (partition of the island) to the Present, relevant information  
218 (defined as contributing significantly to the TEV of Saint-Martin COM) on: geopolitics (column  
219 1); politics (2); institutions (3); tax system and finance (4); law (5) related to town and country  
220 planning (5.1), environment (5.2) and land tenure (5.3); economic activities (6); society (7),  
221 including population growth (7.1), structure by origin, age and socio-economic status (7.2), and  
222 exposure and vulnerabilities (7.3); town and country planning (8) with a focus on urbanization,  
223 infrastructure development and critical services (e.g. water supply, health...); and risk  
224 management (9). Concurrently, public databases (data source 3) were analyzed in two different  
225 ways. The first way consisted in statistical analysis, used to highlight demographic, economic and  
226 societal changes over the period of analysis. The second method used was the setting-up of a GIS  
227 database including information on (1) coastal urbanization, based on the extraction of buildings  
228 and roads at the five dates covered by aerial photographs (1947, 1969, 1984, 1989, 1999) and  
229 satellite imagery (2017), which allowed us to emphasize change in human exposure since 1947;  
230 (2) shoreline change, based on the digitization of the 1947 and 2017 (pre- and post-cyclone)  
231 shorelines, following a well-established protocol (see Duvat *et al.*, 2017b, for long-term shoreline  
232 change and Duvat *et al.*, 2019 for cyclone-related shoreline change); and (3) GIS-derived cross-  
233 cutting statistical analysis, used to estimate the extent and elevation of buildings and roads at  
234 urbanized coastal sites (see location in Fig. 1), and the extent of TC Irma-driven flooding. Post-  
235 cyclone field trips (data source 6) allowed the collection of observations at all coastal sites. These  
236 observations were complementary to satellite image analysis to assess the physical, ecological  
237 (on the vegetation cover) and human (on buildings and infrastructure) impacts of the 2017 TCs.  
238 The TEV and GIS databases firstly allowed us to reconstruct the TEV of Saint-Martin. This was  
239 done by identifying the factors that contributed to the evolution of the system and are a vital link

240 in the causal chain. This led to the formalization (Fig. 2) of the long-term and contemporary  
241 cause-effect relationships (including reinforcing mechanisms contributing to path dependency)  
242 driving changes in exposure and vulnerability over time. These databases were secondly used to  
243 analyze the cascading effects of the 2017 TCs, which were formalized using the same  
244 methodology (Fig. 5). During the analysis phase, findings were discussed through  
245 interdisciplinary (attended by all team members) and more focused (on specific points) virtual  
246 (due to the COVID-19 pandemic) meetings.

### 247 **3. Long-term Trajectory of Exposure and Vulnerability of Saint-Martin**

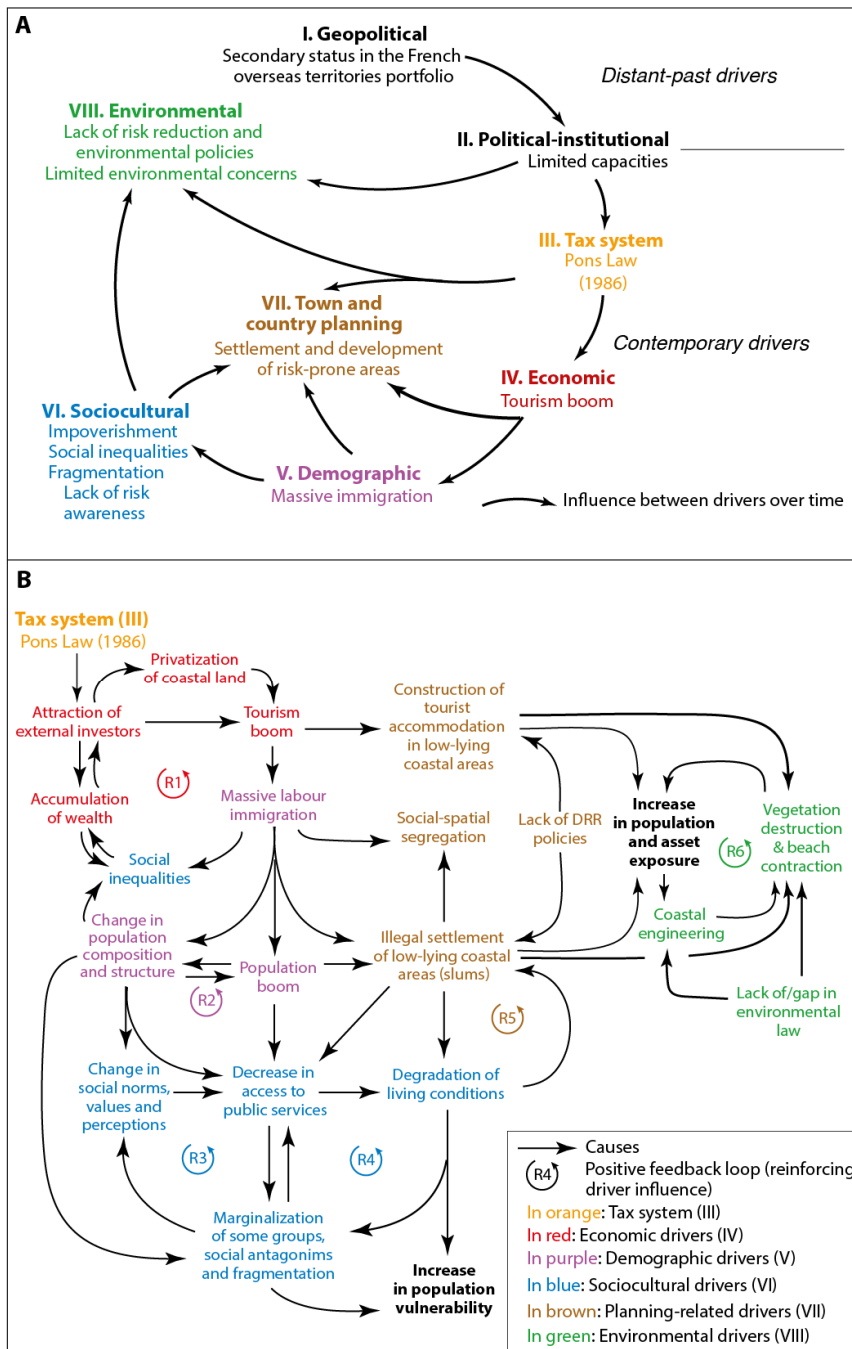
#### 248 **3.1. Analysis of the Trajectory of Vulnerability**

249 Eight interrelated drivers, including geopolitical (I), political-institutional (II), related to the tax  
250 system (III), economic (IV), demographic (V), sociocultural (VI), related to town and country  
251 planning (VII) and environmental (VIII), contributed to the long-term Trajectory of Vulnerability  
252 of Saint-Martin (Fig. 2A). First, the colonization of the island by European countries (from its  
253 partition between France and the Netherlands in 1648 to the decolonization by France in 1946)  
254 has had a major and long-lasting influence on the political status and local institutions of Saint-  
255 Martin (see arrow from driver I to driver II in Fig. 2A), and on its relations with nearby countries,  
256 including the USA and Caribbean islands. Because Saint-Martin had no exploitable natural  
257 resources and limited agricultural potential, it had been attributed a secondary status in the French  
258 colonial portfolio compared to the agricultural islands of Martinique and Guadeloupe. This led to  
259 its annexation to and administration by Guadeloupe (causing ‘double insularity’, Saint-Martin  
260 being the ‘island of an island’) between 1946 (decolonization) and 2007 when it became a COM  
261 endowed with administrative autonomy. This explains not only the structural weakness of local  
262 institutions – the efforts made by the French State to create administrative services locally dates  
263 back to the 1970s-2000s and was limited to specific areas only –, but also the under-  
264 administration of Saint-Martin from the seventeenth century to 1946. This also resulted in the

265 population's mistrust in public authorities, both from mainland France and Guadeloupe, which  
266 further encouraged self-development while also hindering the implementation of national policies  
267 and laws. The under-administration of Saint-Martin has also facilitated its increasing regional  
268 integration over the twentieth century, especially with nearby countries, by encouraging fluxes of  
269 people (out-migration to other Caribbean islands until the mid-1980s, followed by in-migration in  
270 the 1986-1990 period; SM4), foreign investments (especially from the USA from the 1960s to the  
271 1980s, followed by the integration of Saint-Martin in the dollar zone in the 1980s) and goods (of  
272 all kinds, including drugs). In turn, this has further contributed to decrease the local influence of  
273 the French State in Saint-Martin.

274 From the seventeenth century to the mid-1980s, Saint-Martin exhibited limited socioeconomic  
275 development, as a result of limited development potential and public investments. To encourage  
276 its autonomous economic development, France had, since the mid-nineteenth century, exempted  
277 Saint-Martin from taxes, including taxes applying to trade, taxation law and customs duty (driver  
278 III in Fig. 2A). This specific tax exemption regime has been maintained and reinforced over time  
279 despite its relative failure in boosting Saint-Martin's economy. As a result of chronic economic  
280 recession, Saint-Martin has been, until 1986, a poor and sparsely populated island undergoing  
281 chronic emigration whereas Sint Maarten was (since the 1950s) a major tourist destination. In this  
282 context, the adoption of the Pons law (Law n° 86-824, 11<sup>th</sup> of July 1986), exempting from tax  
283 companies and private individuals investing in French overseas territories, triggered an  
284 unprecedented and uncontrolled and therefore anarchical tourism boom in Saint-Martin (driver  
285 IV in Fig. 2). The latter has its roots in the acquisition of vast coastal properties by rich North  
286 Americans from the USA and Europeans (especially from mainland France) following the sale of  
287 State coastal lands from 1955, which resulted in 60% of land being owned by 2% of land owners  
288 in 1979. In 1986, when the Pons law was adopted, the limited (due to continuous emigration) and  
289 unqualified labor force of Saint-Martin could not meet the needs of the construction and tourism

290 sectors. This resulted in massive labor immigration from poor nearby Caribbean islands, such as  
 291 Haiti, the Dominican Republic and Dominica in particular (driver V in Fig. 2). In only a few  
 292 years, the post-1986 immigration resulted in the multiplication of the population by at least 3.6,  
 293 from officially 7,850 inhabitants in 1982 to 28,505 inhabitants in 1990 (SM4). Concurrently, in  
 294 just one decade (1981-1991), the tourism bed capacity of Saint-Martin increased from 487 to  
 295 3,566 beds.



296



297 Fig. 2. Drivers and processes involved in the long-term accumulation of vulnerability and  
298 exposure in Saint-Martin.

299 *Panel A shows how vulnerability has accumulated over the long run (i.e. since the colonization of the*  
300 *island; see SM3 for details). It highlights the major control exerted by historical drivers (I and II) on both*  
301 *recent (that is, post-1980s) development patterns and coastal risk production. The adoption of the Pons*  
302 *Law (1986) exempting investors from taxes (III) has caused a sudden and marked increase in exposure*  
303 *and vulnerability by provoking profound economic (through tourism growth, IV), demographic (through*  
304 *massive immigration, V), sociocultural (VI) and town and country planning-related (VI) changes which*  
305 *have deeply modified both the society (through changes in population numbers, structure and*  
306 *composition) and development patterns (through rapid and widespread coastal urbanization). Panel B*  
307 *focuses on contemporary drivers and illustrates the causal chain linking economic to demographic,*  
308 *sociocultural, town and country planning-related and environmental drivers, as well as the reinforcement*  
309 *of vulnerability and exposure through positive feedback loops (R1 to R6).*

310 Such a massive and sudden immigration caused rapid and profound sociocultural changes (driver  
311 VI in Fig. 2), through changes in population composition (with immigrants representing 72% of  
312 the total population in 1995) and structure (rejuvenation of the population). The high proportion  
313 of immigrants, 75% of which were illegal in 1990, led to major changes in social norms, values  
314 and perceptions, which in turn caused the abrupt marginalization of the native Saint-Martinois  
315 (Jeffry, 2010). This marginalization was (1) linguistic, due to the replacement of the American  
316 English in use in the early 1980s by the French language used by recently-settled French  
317 investors; (2) economic, due to locals' limited skill to invest in tourism; and (3) sociocultural.

318 Sharp antagonisms arose between the natives, the French (from Guadeloupe, Martinique, French  
319 Guiana or mainland France) and immigrants, resulting in social fragmentation. The simultaneous  
320 settlement of the Terres Basses (see location in Fig. 1) by the rich North American and French  
321 investors which triggered economic growth, and of unoccupied and ownerless low-lying coastal  
322 areas (Jeffry, 2010) by poor and exploited illegal immigrants (the situation of most of whom has

323 since then been resolved) living in slums, exacerbated social inequalities and tensions and  
324 generated marked socio-spatial segregation (Moatty *et al.*, 2020). Moreover, the multiplication of  
325 the population by 3.6 in a few years overwhelmed health and education services to such an extent  
326 that the French Senate considered in 1991 that ‘the health safety of the whole municipality [of  
327 Saint-Martin] was threatened’ (Marie, 1991). From the 1990s, limited State investments in public  
328 services and facilities further exacerbated social tensions, while also creating an increasing gap  
329 between evacuation needs and the capacity of public buildings serving as cyclone shelters.

330 Tax exemption artificially boosted tourism investments, to such an extent that bed capacity  
331 rapidly exceeded demand. As a result, from 1990 the tourism sector went into a long-lasting  
332 recession, which caused unemployment among immigrants and, as a consequence, emigration  
333 (SM4). For example, in the late 1990s, 42% of Dominicans and 36% of Haitians were officially  
334 unemployed. This further exacerbated social inequalities and tensions, leading to the  
335 marginalization of a high proportion of immigrants, which in turn encouraged the development of  
336 undeclared employment, illicit activities such as prostitution and drug trafficking, and  
337 delinquency (Redon & Grancher, 2014). Together, gaps in law and the limited enforcement of  
338 law facilitated the development of illicit activities. The economic recession of the 1990s-2000s  
339 further aggravated the impoverishment of immigrants which, together with social housing  
340 shortage, explains the persistence of slums in risk-prone areas until the 2017 TCs (R5 in Fig. 2B).  
341 Together, drivers I to VI and the feedback effects at play (R1 to R4 in Fig. 2B) caused  
342 vulnerability accumulation.

343 As a result of the major socioeconomic changes occurring over the 1980-2000 period, Saint-  
344 Martin had, on the eve of the 2017 TCs, a population composed of 31% of natives, respectively  
345 18% and 16% of people born in other French overseas territories and in mainland France, and  
346 38% of immigrants born abroad (INSEE, 2017). In 2012, 47% of the inhabitants over 15 had no  
347 qualification and only 50% of the 15-64 years age group had a declared job (against 71% in Sint

348 Maarten). The distribution of jobs between the various communities composing the population  
349 revealed high social inequalities. For example, only 10% of those born abroad hold a position in  
350 public services, against 43% of those born in other French overseas territories, 36% of natives  
351 and 32% of those born in mainland France. These various communities also had unequal access  
352 to highly qualified (that is, executive position) jobs: respectively 41%, 17% and 11% of those  
353 born in mainland France, in Saint-Martin and abroad. The minimum wage in Saint-Martin was  
354 two to three times lower than in Sint Maarten despite the advantageous tax exemption regime,  
355 encouraging illegal work and thereby contributing to the persistence of high between-community  
356 social inequalities. The contrasting situations of Saint-Martin (high unemployment rate, but  
357 provision of free educational and health services) and Sint Maarten (offering job opportunities  
358 and connection to the outside world), and high permeability of the border, maintained constant  
359 fluxes of people between the two island sides.

### 360 **3.2. Analysis of the Trajectory of coastal Exposure**

361 Since the mid-1980s, the dramatic increase in population numbers and the tourism boom that  
362 occurred in Saint-Martin have caused the settlement – by immigrants who built slums in  
363 unoccupied areas – and development – as a result of widespread hotel, villa and apartment  
364 construction – of risk-prone very low-lying (< 3 m; see SM6 Table 6) coastal areas (driver VII in  
365 Fig. 2). These latter especially include narrow barrier beaches and submersible coastal plains,  
366 most of which had until then remained free from buildings and infrastructure.

367 In 1947, when Saint-Martin's economy was based on salt production and farming, most low-  
368 lying coastal areas were dedicated to agricultural activities (SM5). The only exceptions were  
369 Grand Case and Marigot bays, which already hosted the two main urban centers covering an area  
370 of 7.5 ha representing at that time 91.8% of the total coastal built area (Fig. 3). As a result of  
371 continuous urban growth over the next decades, these two urban centers covered an area of  
372 31.4 ha representing 86.5% of the total coastal built area in 1984 (SM6 Table 1). The urban

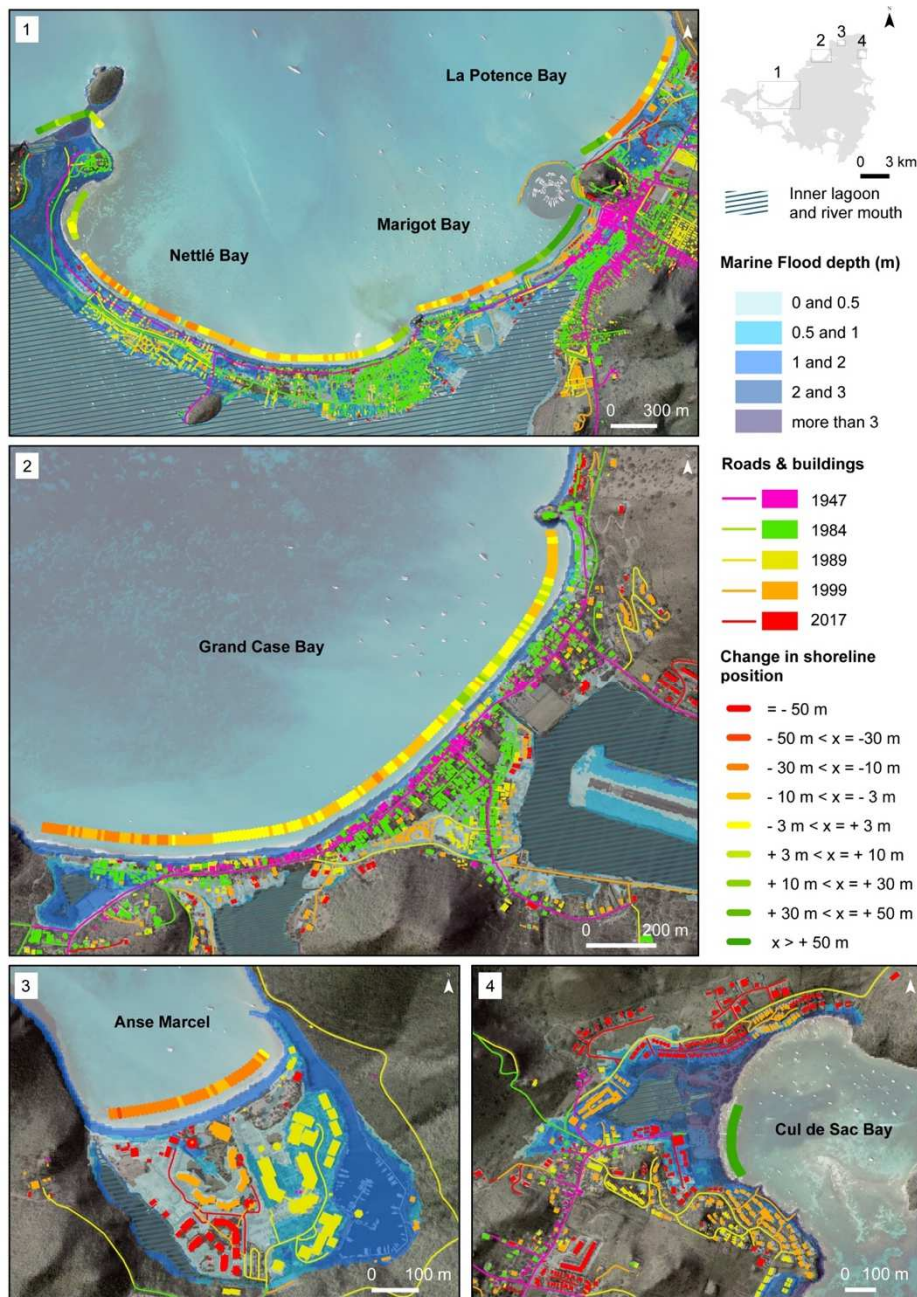
373 center of Marigot, first established at the base of the mountainous slopes, considerably extended  
374 on the submersible barrier beach between 1947 (6.0 ha) and 1984 (25.0 ha) (Panel 1 in Fig. 3).  
375 After 1986, the tourism boom led to the construction of hotels at its north-western end (Nettlé  
376 Bay), which further increased (41.1 ha in 1999, 43.4 ha in 2017) the extent of the risk-prone built  
377 area. Likewise, at Grand Case the urban center (1.4 ha in 1947) expanded on the barrier beach  
378 from the 1980s (6.4 ha in 1984, 9.4 ha in 1999 and 10.4 ha in 2017).

379 Outside these two urban centers, the built area spread from 0.7 ha in 1947 to 35.6 ha in 2017,  
380 with a marked increase after 1986 (Pons Law), from 4.9 ha in 1984 to 12.4 ha in 1989  
381 (multiplication by 2.5 in only 5 years) and 25 ha in 1999 (twofold increase in just one decade), as  
382 a result of the construction of marinas (e.g. at Anse Marcel; Fig. 3), seaside residences (at Cul de  
383 Sac Bay, Longue Bay, Plum Bay, Red Bay; Figs. 3 and 4) and hotels (at Orient Bay and Lucas  
384 Bay; Fig. 4) on low-lying barrier beaches and in coastal plains. Over time, increasing land  
385 scarcity encouraged construction on upper beaches and in marshy and riverbank risk-prone areas  
386 (e.g. at Orient Bay and Anse Marcel). This was facilitated by the sale of risk-prone land included  
387 in the public coastal zone to private individuals and companies (only prohibited in 2015), and by  
388 the lack of enforcement of law prohibiting construction in these areas. In addition, illegal  
389 occupancy and construction were encouraged by successive regularizations of illegal occupation  
390 of the coastal zone belonging to the State in 1986 and 1996, and by the absence of police control  
391 and legal proceedings (SM3). Moreover, the transfer of the town and country planning  
392 competence to Saint-Martin COM in 2012 resulted in the relaxation of former national rules, as  
393 shown by the authorization of construction in low-density urbanized areas where construction  
394 was previously prohibited. Airports and roads were also constructed in risk-prone areas. Both  
395 Juliana and Grand Case airports (Panel 2 in Fig. 3) were constructed on reclaimed land in inner  
396 lagoons, which exposes them to marine and river flooding. Likewise, roads located in low-lying

397 coastal areas exhibited a fourfold increase in length from 1947 to 2017, from 24.1 to 103.3 km,  
398 with road length nearly doubling in these areas since 1984 (SM6 Table 2).

399 The heavy devastation caused by TCs Luis (1995) and Lenny (1999) did not cause any change in  
400 development and land use patterns. Some heavily devastated hotels and tourist residences were  
401 not repaired (Magnan, 2008), because tax exemption had come to an end, pushing investors to  
402 quest for profit elsewhere. That said, most coastal habitations and hotels were restored or rebuilt  
403 identically in the same place, with some of them being protected by engineered structures after  
404 reconstruction. After these TCs, the built area exposed to sea-related hazards continued to  
405 increase. However, the vulnerability of buildings decreased, as a result of the rehousing of most  
406 slum residents (with the exception of Sandy Ground inhabitants, Nettle Bay) in social housing  
407 (from nonexistent to 1430 units in 1999; IEDOM, 2007).

408 Over the 1947-2017 period, most beach sites underwent marked shoreline retreat (Figs. 3 and 4;  
409 SM7 Table 1), except Cul de Sac (+100.6 m) and Marigot (+24.4 m) bays, where land  
410 reclamation caused shoreline advance, and Plum and Longue bays, which underwent naturally-  
411 driven shoreline advance (+7.0 m and +7.7 m, respectively). Shoreline retreat was the highest at  
412 Orient Bay (−47.3 m on average). Minimum shoreline retreat values were of between −10 to −  
413 30 m at Red Bay, Nettle Bay, Marigot Bay and Grand Case Bay, and of between −30 m and −  
414 50 m at Anse Marcel. The combination of the seaward advance of buildings and the landward  
415 migration of the shoreline had two major impacts, namely the destruction of the native coastal  
416 vegetation and beach contraction, which further increased human asset exposure to sea-related  
417 hazards over time (R6 in Fig. 2B).

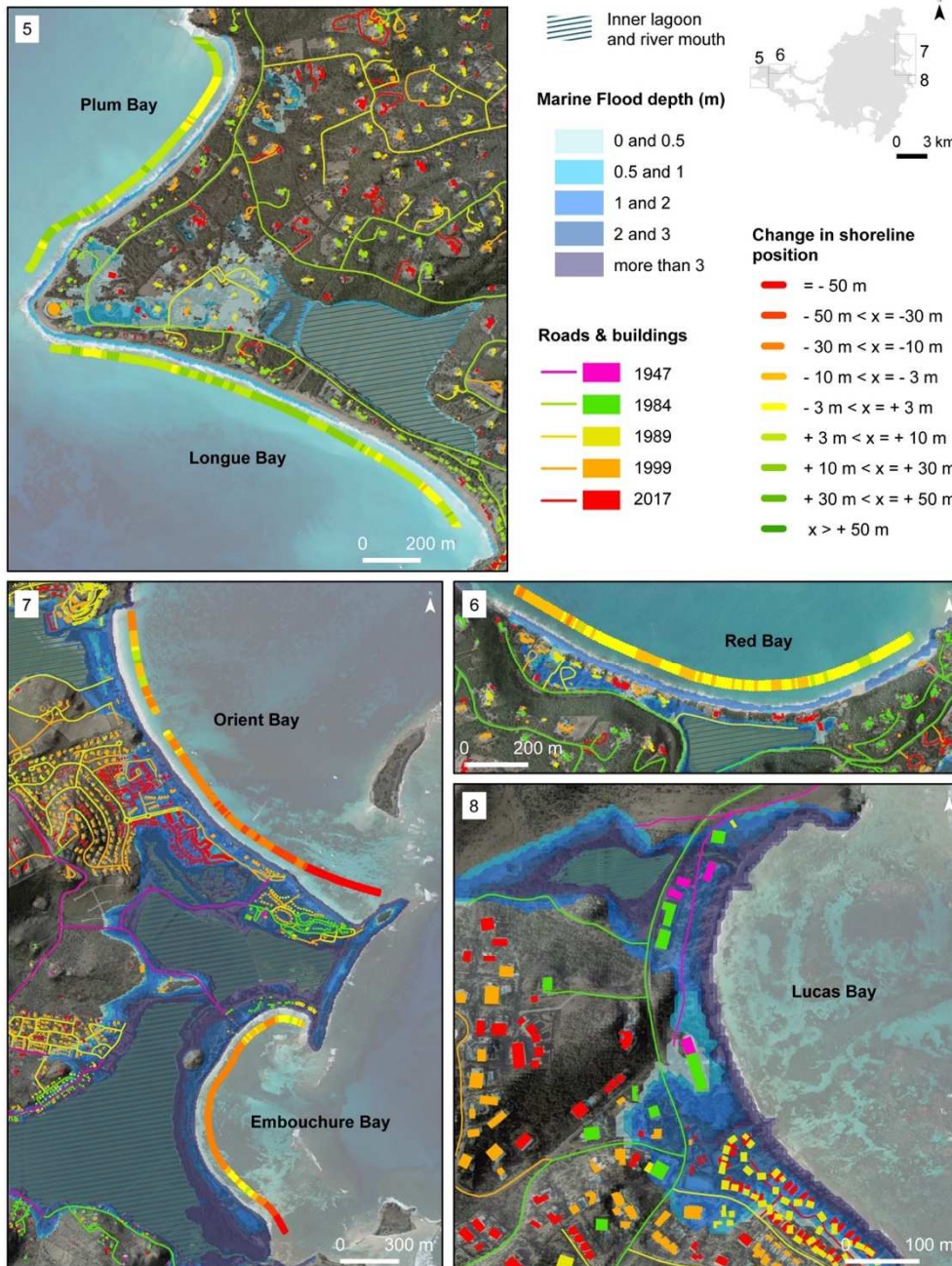


Made from the data BD PARCELLAIRE 2015, BD ALTI 2017, ROUTE ADRESSER 2017, BD ORTHON 2017 and 1947, 1984, 1989, 1999 aerial images © IGN. Pleiades satellite images acquired on February 12, 2017 © CNRS, 2017, distributeur AIRBUS DS, France, all rights reserved. Marine flood depth: Cerema © IGN, Guadeloupe, 2017.

418  
 419 Fig. 3. 1947-2017 increase in human asset exposure to sea-related hazards at northern beach sites  
 420 in Saint-Martin.

421 *This figure shows four of the most densely settled and developed coastal sites, including the two urban*  
 422 *centers of Marigot (1) and Grand Case (2), Anse Marcel marina (3) and the residential and tourist bay of*  
 423 *Cul de Sac (4). While the two urban centers experienced continuous growth between 1947 and 2017, the*  
 424 *other sites showed marked seaside development from 1986 (Pons Law). These maps also highlight the*  
 425 *alongshore and seaward expansion of the built area over the past decades, with the most recent*

426 constructions being the closest to the sea. Additionally, they show the prevalence of shoreline retreat  
 427 (shoreline change  $< -3$  m) along shorelines (unknown for 4). At most sites, the combination of seaward  
 428 urbanization and shoreline retreat increased building and road exposure to sea-related hazards. Last, this  
 429 figure shows for each beach site the extent of the area that was flooded during tropical cyclone Irma, as a  
 430 result of wave incursion, rainfall and river and lagoon flooding, as well as the depth of flooding.



431  
 432 Fig. 4. 1947-2017 increase in human asset exposure to sea-related hazards at western and eastern  
 433 beach sites in Saint-Martin.

434 *This figure shows changes in exposure in the rich residential area of the Terres Basses (5, 6) as well as at*  
435 *the main tourist sites (7, 8). It emphasizes the recent (post-1980s) development of most sites, with the*  
436 *exception of Lucas Bay, as well as contrasting long-term shoreline changes (prevalence of shoreline*  
437 *retreat or advance, depending on sites) and the widespread flooding caused by TC Irma at these sites.*

438

### 439 **3.3. Governance drivers of vulnerability and exposure**

440 The continuous and dramatic increase of exposure and vulnerability in Saint-Martin was also due  
441 to the late adoption and limited implementation of national DRR and environmental policies in  
442 this territory (int\_No.4, int\_No.5, int\_No.6). The French DRR policies designed in the second  
443 half of the 20<sup>th</sup> century applied to overseas territories late after their implementation in mainland  
444 France (SM 8). The ‘Barnier fund’ for the prevention of major natural hazards (1995), which  
445 addresses both prevention and reparation, was the first measure applying simultaneously to  
446 mainland France and the overseas territories ruled by the national environmental code, including  
447 Saint-Martin. However, because it mainly addresses short term emergencies – except for the  
448 design of Risk Prevention Plans (PPR, Plan de Prévention des Risques in French, French State  
449 competence) (Lambert *et al.*, 2019) – this fund did not contribute much to the reduction of long-  
450 term exposure and vulnerability in Saint-Martin. The PPR of Saint-Martin was only adopted in  
451 2011 despite the heavy damages caused by TC Luis in 1995. This considerably limited the  
452 benefits of this plan for reducing building and road exposure to sea-related hazards, all the more  
453 as (i) the alignment of the 2002 Land Use Plan with the PPR failed (int\_No.3), (ii) no strategic  
454 and managed retreat was planned in Saint-Martin, (iii) the tacit rule applying after disasters, that  
455 is, identical reconstruction, contributed to the maintenance of population and human asset  
456 exposure over time (Barraqué & Moatty, 2019). Moreover, the structurally low (with limited  
457 change observed after the 1990s TCs; Calvet *et al.*, 2011) coverage of house insurance in Saint-  
458 Martin (40% against 52-53% in Guadeloupe and Martinique and 98% in mainland France before



459 the 2017 TCs; with a similar situation noted in Sint Maarten; PEARL, 2018) contributed to the  
460 persistence of high population vulnerability to climate-related events as cyclonic damage is only  
461 compensated for those who are insured. Population exposure to the impacts of the 2017 TCs was  
462 further amplified by gaps in building code specifications – which are unsuitable for intense TCs –  
463 and their limited implementation in Saint-Martin.

464 Regarding crisis management, the French State (Prefect) and Saint-Martin COM (President)  
465 share responsibilities. They are respectively in charge of the ‘civil protection organization plan’  
466 (ORSEC plan) and the ‘territorial safety plan’ organizing early warning, information and  
467 protection of the population. In Saint-Martin, despite it became compulsory in 2013, the first  
468 ‘territorial safety plan’, was adopted in March 2017 only (int\_No.6). Before the 2017 TCs, the  
469 capacity of cyclone shelters was only of 900 people, while needs were estimated at ~7,000  
470 people.

471 Likewise, gaps in environmental policies encouraged coastal urbanization. The French Coastal  
472 Law of 1986, which forbids urbanization within a 81.2 m-wide coastal strip from the high water  
473 mark in overseas territories, was lightened for application in these territories (from 1996 only),  
474 with possibilities to regularize former illegal occupations. Because of this and because it is not  
475 fully implemented in Saint-Martin (int\_No.3, int\_No.4, int\_No.7), this law failed in preventing  
476 coastal urbanization. This has in turn contributed to shoreline hardening, with building frontage  
477 acting as seawall and thereby exacerbating cyclone wave-induced erosion (e.g. in 1995), which  
478 further increased population and human asset exposure to sea-related hazards (R6 in Fig. 2).

479 More generally, widespread environmental degradation (driver VIII in Fig. 2), including the  
480 clearing of the native terrestrial and intertidal (mangrove) vegetation, the reclamation of inner  
481 lagoons (which exacerbates flooding), shoreline armoring, sand dune flattening and accelerated  
482 marine ecosystem (seagrass beds, algal and coral habitats) degradation, has, since the mid-1980s,  
483 significantly increased population and human asset exposure. The protection of coastal and

484 marine environments was only recently initiated through the creation of a National Nature  
485 Reserve in 1998 and the first acquisitions of coastal land (that cannot legally be built on after  
486 acquisition) by the national Coastal Conservatory in 2003 (int\_No.4; Fig. 1).

487 At an international level, cooperation with Sint Maarten and European Union funds had a limited  
488 influence on the TEV of Saint-Martin. Cooperation between Saint-Martin and Sint Maarten in the  
489 area of risk management was indeed very limited until the 2017 TCs. Despite Saint-Martin COM  
490 can access European Union funding, the latter was not much solicited by Saint-Martin for  
491 exposure and vulnerability reduction. This is due to limited political commitment in DRR and  
492 reduced human capacities and skills. Likewise and for the same reasons, national funding aimed  
493 at reducing risks was little requested by Saint-Martin COM.

494

#### 495 **4. Relationship of long-term TEV to 2017 tropical cyclones' impacts**

496 The analysis reveals how the cyclones activated the historical causal chain controlling exposure  
497 and vulnerability to generate cascading effects – from direct first order impacts to systemic  
498 disaster; Fraser *et al.*, 2016; Menoni & Boni, 2020 – that drove the system out of equilibrium  
499 (Pescaroli & Alexander, 2015). Both the rapid propagation of impacts from one area to another  
500 and the amplification of impacts at ‘escalating points’ (Alexander, 2018) resulted in systemic  
501 disruption in less than two weeks. Here, we successively highlight the relationships of the long-  
502 term Trajectory of Exposure to TCs’ impacts, and the contribution of increased post-cyclone  
503 exposure to the propagation and amplification of vulnerability.

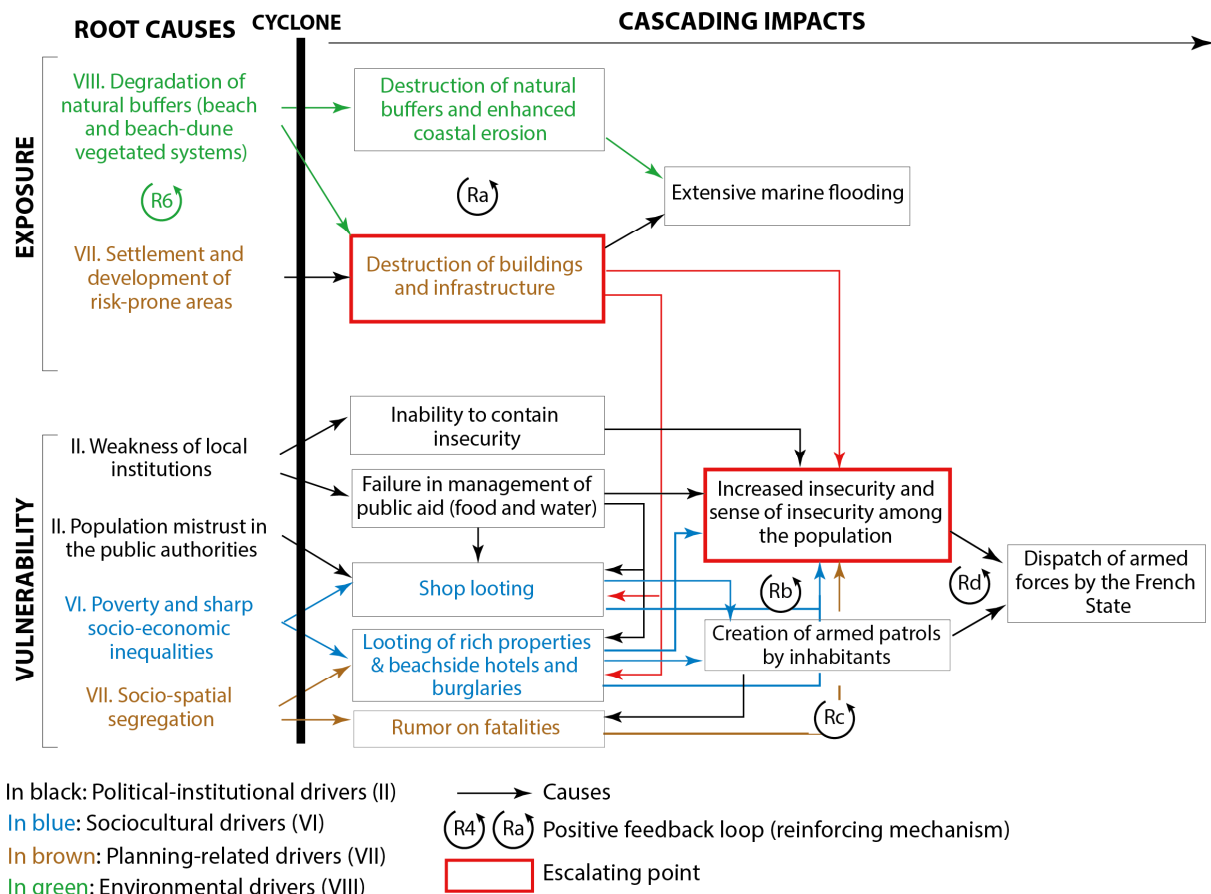
#### 504 **4.1. Relationship of long-term Trajectory of Exposure to coastal impacts**

505 The very high exposure of buildings, infrastructure and roads to cyclonic waves, due to their  
506 concentration in low-lying (<5 m in elevation; SM6 Tables 3 and 5) and unstable (barrier and  
507 upper beaches, swampy areas) coastal areas (driver VII in Fig. 2), significantly contributed to

508 their devastation by the 5 to 9 m high waves generated by TC Irma (Duvat *et al.*, 2019). At  
509 highly-developed beach sites – which are the most represented –, the degradation or absence of  
510 natural buffers, namely vegetated beach-dune and upper beach systems (driver VIII in Fig. 2A  
511 and feedback loop R6 in Figs. 2B), considerably exacerbated the devastation of human  
512 constructions by waves (Duvat *et al.*, 2019; Rey *et al.*, 2019). The first line of buildings and  
513 narrow introduced-vegetation (coconut trees) belt acted as a barrier to waves and underwent  
514 complete washing out (e.g. Orient Bay) or severe damage (e.g. Nettlé Bay). Wave reflection on  
515 human constructions also amplified shoreline retreat, beach contraction (SM7 Table 2) and  
516 vegetation destruction, thereby reinforcing the exposure of these constructions to waves  
517 (feedback loop Ra in Fig. 5). Eight out of the twelve sites considered in this study predominantly  
518 exhibited erosion, which was detected along 71.1% to 100% of the shoreline (Figs. 3 & 4), with  
519 high mean (up to –68.3 m) and maximum (up to –166.5 m) retreat values. Shoreline stability  
520 prevailed (i.e. was detected along 59.2 to 88.6% of the shoreline) at two sheltered (Plum and  
521 Longue bays) and two armored sites where engineered structures withstood waves (La Potence  
522 and Marigot bays). In urbanized areas, shoreline hardening also prevented wave- and wind-driven  
523 sediment deposition inland, thereby hindering the activation of a negative (that is, balancing)  
524 feedback effect that might have contributed to the reduction of exposure. In contrast, highly-  
525 exposed natural sites exhibiting no or little human modification experienced not only more  
526 limited shoreline retreat (e.g. –18.8 m for mean and –28.9 m for maximum values at Petites  
527 Cayes Bay; Duvat *et al.*, 2019), but also significant sediment accumulation reflected by beach  
528 formation, beach crest upward growth (through sediment interception by the native vegetation)  
529 and/or sediment accumulation on beaches and upper beaches. The highly contrasting impacts of  
530 cyclonic waves between densely urbanized sites (exhibiting positive feedback effects) and natural  
531 beach sites (exhibiting negative feedback effects) highlight the major role of development  
532 patterns in influencing both the nature (predominantly erosional vs. constructional) and

533 magnitude (through shoreline retreat and sediment loss) of impacts. By amplifying sediment loss  
534 and preventing sediment deposition, coastal urbanization also exacerbated population and human  
535 asset exposure following TC Irma, which amplified the destructive effects of TC José's waves on  
536 human constructions.

537 Similarly, the establishment of human constructions in low-lying coastal areas over the recent  
538 decades, together with the destruction by TC Irma's waves of the first line of buildings  
539 (escalating point in Fig. 5) and vegetation belt, led to extensive flooding of settled areas (Figs. 3,  
540 4 & 5). Depending on sites, 11.2 to 70.7% of the built area were flooded by TC Irma's waves  
541 (SM6 Table 4). The highest flood rates occurred at Anse Marcel marina (70.7%) and at the urban  
542 centers of Grand Case (51.9%) and Marigot (53.9%), due to the construction of 61.6 to 94.0% of  
543 buildings at elevations of less than 3 m (SM6 Table 3). Likewise and for the same reasons,  
544 coastal roads were extensively flooded (SM6 Table 6), including at Marigot (59.4% of the road  
545 network flooded) and at major tourist sites (e.g. Orient Bay, 46.3%) (SM6 Table 5).



546

547 Fig. 5. Cascading impacts of the 2017 tropical cyclones in Saint-Martin.

548 *This figure highlights the connection between the root causes of exposure and vulnerability and*  
 549 *impacts, as well as the amplifying effects associated with the propagation of impacts, especially*  
 550 *at escalating points.*

551

552 **4.2. Relationship of long-term Trajectory of Vulnerability to impacts**

553 The root causes of vulnerability, including especially the weakness of local institutions and  
 554 population mistrust in public authorities (driver II), poverty and sharp socio-economic  
 555 inequalities (driver VI), and marked socio-spatial segregation (driver VII), amplified the  
 556 cascading effects generated by the TCs (Fig. 5). Interestingly, the rapid and massive intervention  
 557 of the French Government to both address immediate population needs and prevent misbehaviors  
 558 after the passage of TC Irma failed in containing the propagation and amplification of its impacts.

559 First, the public authorities activated the emergency response (early warning, evacuation and  
560 preparation of rescue teams in Guadeloupe) the day before TC Irma hit Saint-Martin (Moatty *et*  
561 *al.*, 2019). Second, the Minister of Overseas Territories and President of the Republic reaffirmed  
562 the State's authority and support to Saint-Martin during their post-cyclone visit. Third, the public  
563 authorities ensured the initial presence (from the day before landfall, when police officers  
564 encouraged inhabitants living in coastal areas to evacuate to cyclone shelters; int\_No7) and  
565 reinforcement of the forces of order (up to 1,200 military staff deployed on the ground in late  
566 September; int\_No.7) to ensure security and help clean the main roads (int\_No.7). They also sent  
567 the Emergency Preparedness and Response Health Establishment team (int\_No.5) and 400 young  
568 people from the Adapted Military Service on site to provide assistance to the population, as well  
569 as 1,800 tons of freight, 2 million bottles of water, 35,000 military rations and 50,000 m<sup>2</sup> of  
570 tarpaulins (Ministère des Outre-Mer, 2018).

571 Despite such a response by the French Government, Saint-Martin experienced increased  
572 insecurity and sense of insecurity in the aftermath of the TCs. Population mistrust in public  
573 authorities, which has its roots in centuries of under-administration and self-development of  
574 Saint-Martin, manifested through inhabitants' view that they could not rely on immediate public  
575 aid for food and water after the cyclone. This, added to the possibility to resell goods (reflecting,  
576 within some population groups, self- and pecuniary interests), led to widespread shop looting,  
577 which increased insecurity and the sense of insecurity among the population (positive feedback  
578 loop Rb in Fig. 5). Interviewed inhabitants invoked the lack of human and logistical resources to  
579 organize the delivery of food and drinking water, and clean up Saint-Martin. Based on our  
580 investigations, it seems that the gap between officials' (invoking massive logistical and first aid  
581 support to Saint-Martin) and inhabitants' testimonies comes from the inability of local public  
582 authorities to allocate efficiently the resources that were sent by the French Government and

583 NGOs. This was due to various factors including, on top of the succession of two TCs in less than  
584 two weeks, the limited human and logistical capacities of local institutions and corruption.

585 At the same time, the extensive destruction of buildings in coastal areas, including the washing  
586 out of doors and windows by the cyclonic winds and waves (section 4.1), and preexisting  
587 socioeconomic inequalities between wealthy primary and secondary residents (insured) and poor  
588 people, including those living in coastal slums (not insured), encouraged widespread looting of  
589 rich properties and hotels. This highlights the interconnection between exposure and  
590 vulnerability, with the destruction of dwellings and hotels acting as an escalating point in the  
591 propagation of impacts. Interviewees recounted looting by armed groups and shooting, but  
592 without injury. They referred to looting as ‘a second cyclone’, with some of them considering  
593 that ‘burglaries [had] caused more damage than the cyclones’. The inability of the police force to  
594 contain incivilities and looting (driver II) further exacerbated fear and created a strong sense of  
595 abandonment among inhabitants, prompting them to create armed patrols to protect their  
596 properties and families, which further amplified insecurity and the sense of insecurity (positive  
597 feedback loop Rb) among communities. The Terres Basses wealthy residential area (Fig. 1) was  
598 placed under police control and closed to the public, with villa owners employing private  
599 companies to secure their properties. Insecurity was particularly felt by those who had suffered  
600 heavy dwelling destruction and had no prospect of leaving the island, including the natives (who  
601 had no other place to go) and the poor (who did not have the financial resources to leave). This in  
602 turn led to the disproportionate dispatch of French armed forces (Moatty *et al.*, 2019), which  
603 further exacerbated the sense of insecurity among the population (positive feedback loop Rd).

604 Marked socio-spatial segregation (Redon, 2007) acted as an amplifier of the sense of isolation  
605 and insecurity felt by the most affected families across communities. Because residents generally  
606 did not know nor trust neighboring communities, they suspected these latter of burglary and  
607 shooting, and reciprocally. Socio-spatial segregation also explained that communities did not get

608 clear information on what was really happening around them, which progressively led to the  
609 emergence of the collective belief that the cyclone had caused hundreds to thousands of victims  
610 (Moatty *et al.*, 2020). Such a rumor, which persisted for more than a year, strongly contributed to  
611 reinforce the sense of insecurity and distress at the whole island scale (positive feedback loop  
612 Rc).

613

## 614 **5. Benefits of a long-term TEV approach to understand path-dependency**

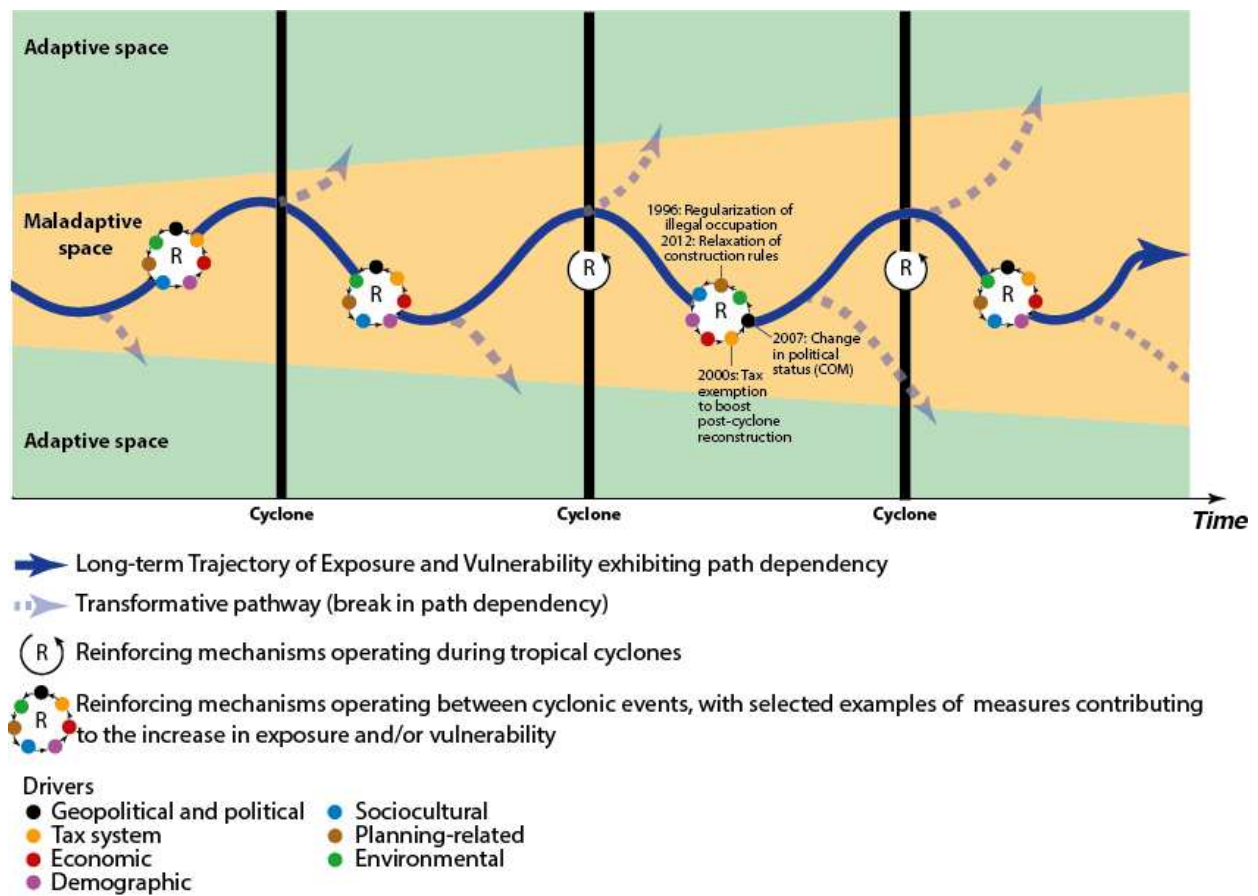
615 The reconstruction of the long-term TEV of Saint-Martin through the investigation of the causal  
616 chain linking geopolitical and political-institutional drivers to other areas (including legal,  
617 economic, demographic, sociocultural, town and country planning-related and environmental),  
618 highlights strong and deeply-enrooted (into three centuries of history) path dependency  
619 embedded within complex local-to-national political-institutional functioning (Fig. 6). Since  
620 colonial times (17<sup>th</sup> century), limited state commitment in the development of Saint-Martin's  
621 institutions and economy has paved the way to the dramatic effects generated by the tax  
622 exemption law of 1986, which is the root of population exposure and vulnerability to sea-related  
623 hazards. Furthermore, despite its failure to promote long-lasting and fair socioeconomic  
624 development and its major role in first causing and then constantly reinforcing population  
625 exposure and vulnerability (through economic recession and increased social inequalities), tax  
626 exemption has been maintained by the national public authorities as the main incentive to  
627 economic development and a solution to recession. It has generated an unsustainable and risk-  
628 prone development model that has persisted until 2017 despite the heavy devastation caused by  
629 TC Luis in 1995. The primacy placed on economic development at the cost of risk reduction is  
630 reflected in the way law has been used to allow for the pursuit of coastal urbanization: 1986 and  
631 1996 laws regularizing illegal occupation; 2012 relaxation of national law to authorize additional  
632 construction; pursuit of the sale of public risk-prone coastal land to private companies and



633 individuals until 2015 despite the PPR being included in the 1995 law (SM3). In the same way as  
634 in Sint Maarten (Fraser *et al.*, 2020), the increased autonomy of Saint-Martin from 2007 has  
635 further weakened local institutions and political will (as a result of political instability, corruption  
636 and patronage system) and strengthened the local push for shortsighted coastal development.  
637 Thus, instead of creating a window of opportunity for breaking path dependency (purple arrows  
638 in Fig. 6), this new institutional arrangement has reinforced risk-prone values within institutional-  
639 political spheres locally (a powerful barrier to transformation; Jeffers, 2013; Magnan & Duvat,  
640 2018), which has in turn fueled the expectations of investors and the general public for the  
641 maintenance of the land use and building status quo (a mechanism described by Parsons *et al.*,  
642 2019). The example of Saint-Martin thus highlights the strong control exerted by institutional-  
643 political drivers in creating path dependency that maintains a territory on a maladaptive trajectory  
644 (Fig. 6).

645 In Saint-Martin as in other territories exhibiting similar weaknesses in the face of natural  
646 disasters (e.g. nearby Sint Maarten, Collodi *et al.*, 2019; Medina *et al.*, 2019; Medina *et al.*, 2020;  
647 Fraser *et al.*, 2020), breaking path dependency therefore firstly implies to align local institutional  
648 capacities with national risk reduction and environmental policies so as to ensure that these  
649 policies are fully implemented locally. In Saint-Martin, this would allow reducing population and  
650 human asset exposure. Addressing path dependency secondly requires to reduce inequalities and  
651 promote social justice (Lebel *et al.*, 2006; Thomas *et al.*, 2018), and to foster community  
652 engagement in decision making (Holdschlag & Ratter, 2015; Borges-Méndez & Caron, 2019;  
653 Parsons *et al.*, 2019). Promoting social justice would indeed help to secure the livelihoods and  
654 habitations of the most vulnerable (Lebel *et al.*, 2006; Collodi *et al.*, 2019), which would in turn  
655 help to anticipate increased insecurity during cyclonic events. At the same time, fostering  
656 community engagement in decision making could help to tackle two strong barriers to the

657 breaking of path dependency in Saint-Martin, including short-sighted decision-making promoted  
 658 by the elite and risk-prone forms of knowledge.



659

660 Fig. 6. Conceptualization of the maladaptive development trajectory of Saint-Martin.

661 *Building on previous conceptualizations of adaptation pathways (Wise et al., 2014; Parsons et*

662 *al., 2019), this figure formalizes the path dependency maintaining Saint-Martin in the*

663 *maladaptive space, as well as the contribution of recurring cyclonic events and law to the*

664 *reinforcement of exposure and vulnerability over time. The enlargement of the yellow*

665 *background illustrates lock-in into the maladaptive space and the subsequent need for increased*

666 *efforts to implement transformative pathways (shown by increasing length of dotted arrows).*

667

668

669

## 670 **6. Conclusions**

671 Using the example of Saint-Martin, this article shows the major role of historical geopolitical and  
672 political-institutional drivers and of the causal chain linking them to other areas (including legal,  
673 economic, demographic, sociocultural, planning-related and environmental) in causing the  
674 accumulation of exposure and vulnerability to climate-related hazards over time in formerly  
675 colonized territories. Context-specific practices (especially the use of tax exemption as an  
676 incentive to economic development and a solution to economic recession) embedded within  
677 political-institutional functioning (limited state commitment leading to under-administration, and  
678 gaps in law and the implementation of law) have fueled reinforcing mechanisms that have  
679 contributed to the propagation and amplification of risks and disasters over time, as illustrated by  
680 the cascading impacts of the 2017 tropical cyclones. Together, the reinforcing mechanisms  
681 operating between (rapid and unplanned coastal urbanization and inequitable economic  
682 development) and during (through cascading effects and escalating points) cyclonic events have  
683 created strong and long-lasting path dependency that has maintained Saint-Martin on a  
684 maladaptive trajectory.

685 These findings firstly confirm the relevance of historical approaches aimed at reconstructing the  
686 Trajectory of Exposure and Vulnerability of territories to identify which levers could be activated  
687 to break path dependency and thereby promote risk reduction and climate adaptation. In small  
688 islands and other territories exhibiting strong legacies of colonization and globalization (e.g.  
689 Barclay *et al.*, 2019; Bordner *et al.*, 2020; Duvat *et al.*, 2017; Look *et al.*, 2019; Moulton &  
690 Machado, 2019), multi-centennial backward-looking and cross-scale (from local to international)  
691 empirical studies as this one are particularly needed to identify these levers. Secondly, this study  
692 demonstrates the need for interdisciplinary approaches including social and physical scientists to  
693 investigate all of the multiple facets of risk and interrogate interdependencies between both the

694 components of the considered territorial system (at the local scale) and this system and higher-  
695 level (that is, national to international) systems.

696

## 697 **References**

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