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Roads of the Caribbean: regional analysis from Environmental Impact Assessments in Colombia

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Abstract. Road infrastructure produces several impacts on the environment. In the Colombian Caribbean region, the growing road infrastructure threatens systems equilibrium in diverse and not well-known ways. Functional limitations on the administrative tools available in Colombian legislation to manage infrastructure impacts mean that an overall assessment of the interconnected regional ecosystems falls out of scope. In this study, Environmental Impact Assessments of eight (8) road construction projects were evaluated to determine how the large-scale problems of hydrologic and ecologic connectivity, or landscape fragmentation, are considered. The scientific literature is critically examined to identify possible unseen problems and future challenges relating to road construction in the Caribbean. The results suggest that Environmental Impact Assessments for each project establish typified or preset management measures, focus on construction processes, and ignore accumulative and residual effects. Thus, the study recommends integrated analysis for future projects that includes a detailed understanding of the alterations to regional landscape and water systems.

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1. Introduction

Road infrastructure can bring many economic and social benefits, but its impact on nature and the environment can be innumerable. Road construction and traffic are among the main causes of natural habitat loss, but knowledge on the actual negative effects in Latin American countries is still lacking (Pinto et al., 2020). The scientific literature review offers abundant studies describing the impacts of roads infrastructure on the environment, such as fragmentation of the natural landscape (Wu et al., 2014; Ascensão et al., 2019) and loss of biodiversity (Brejão et al., 2020), water resources (Golden et al., 2014), and habitat. Such impacts thus affect ecological functions (Bunn & Arthington, 2002; Bracken et al., 2013), geomorphological dynamics (Thompson et al., 2008; Keesstra et al., 2018), and even the wellbeing and quality of life of communities themselves (Condurat et al., 2017; Foley et al., 2017; Khan et al., 2019).

The observable effects on aquatic or amphibian ecosystems due to road infrastructure are varied, ranging from, for example, roadkill (Sássi et al., 2013) through the drying of swamps due to changed sediment dynamics (Keesstra et al., 2018), to loss of the river-floodplains interaction (Brejão et al., 2020). Thus, the construction of a road imposes a linear barrier that interrupts all sorts of flow on both sides of the construction site. The barrier usually fragments the territory and creates so-called edge and barrier effects, thereby discontinuing structural connectivity, which in turn changes the flows of natural materials, energy, and information (Gurrutxaga, 2011). The loss of connectivity results in significant transformations in balance, stability, and ecological functionality (Pavlickova & Vyskupova, 2015). The loss of connectivity must not be addressed solely from the terrestrial ecosystems or landscape standpoints, as it also causes disconnections in water systems (Saunders et al., 1999; Freeman et al., 2007), and freshwater (Langen et al., 2012; Gutiérrez-C. & Pinilla-A., 2016; Jaramillo, Brown, et al., 2018; Jaramillo, Licero, et al., 2018), marine and coastal ecosystems.

In Colombia, road infrastructure development has mainly been concentrated in the Andean region and the Caribbean. The country passed from having 718 km of dual carriageway to 1,240 km between 2010 and 2017 (Mintransporte, 2018). In the Caribbean region, the growing development of road infrastructure is coupled with active socio-economic dynamics and a variety of bio-geographical conditions ranging from paramos to the numerous wetland systems such as mangroves, estuaries, swamps and coastal lagoons, and the Magdalena River alluvial plain. In this scenario, increasing pressures are being exerted on the region's ecosystems. For example, since the construction of the Barranquilla–Ciénaga highway in 1956, The Large Marsh of Santa Marta (*Ciénaga Grande de Santa Marta – CGSM*) has lost a significant amount of mangrove forest cover, and it lost 48% of sea-swamp connectivity between 1956 and 2005 (Espinosa et al., 2005). Other examples include the building of a ring road in 1988 near the Marsh of *La Virgen* in Cartagena, causing ecological disasters (IAVH and PUJ, 2015). Nevertheless, research and publications in Colombia and the Caribbean Region have paid little attention to the impact of road construction projects.

The set of regulatory instruments to identify, manage and mitigate environmental impacts of infrastructure works in Colombia includes Environmental Diagnoses of Alternatives, Environmental Management Plans, and Environmental Impact Studies (EIA); all of them within the process of environmental licensing. One limitation of environmental licensing for road infrastructure works in Colombia remains the fact that the applicant is responsible for choosing the methodology to assess the effects of the road infrastructure provision on the ecosystem; thus, the objectivity and rigor of the process could be put into question (Toro et al., 2010; Soto et al., 2018).

According to local experts consulted in a regional scientific seminar, the real environmental impacts with special concern for regional/systematic effects of road infrastructure development are not effectively studied nor understood. Pinto (2020) points out a lag between the progress on road infrastructure in Latin America and the scientific efforts for actual comprehension of transportation infrastructure impacts and the cumulative effects on the ecosystem at the landscape level. Given the lack of studies, managers base their decisions and control measures on EIAs. In the opinion of local experts, EIAs fail to recognize and deal with diverse, complex, and systemic effects, such as those referred to by the scientific literature. Extended and numerous studies are required to characterize regional effects of road infrastructure in the Colombian Caribbean. Meanwhile, we contrast the more or less standardized information and methodologies from EIAs of road construction projects against the wide variety of impacts evidenced by the scientific literature. Thus, in this study, we test the hypothesis that the EIAs of road infrastructure in the Colombian Caribbean do not account for a wide range of the environmental effects identified by the scientific literature. In that way, we offer a methodology to support experts' concerns. And, at the same time, we describe, alert, and call the local researchers' attention to an unseen environmental problem.

Recently, several methodological approaches were applied to assess the quality of EIAs (Mateichyk et al., 2021; Aung & Fischer, 2020; Nita et al., 2022). After a couple of decades of massive application of EIAs methodologies and research, there exists a common opinion to move on to reexamining EIA procedures, innovating legislation, and implementing practices (Nita et al., 2022). This study does not intend to evaluate the quality of EIAs per se but to use them as a stencil sifter to shed light on a problem – a problem that is described from the experience, perception, and concern of local experts. Still, a methodology to contrast, check or evaluate every project EIA is needed. Since there is no defined numerical methodology to evaluate EIAs' effectiveness in a region, it is convenient to use qualitative methods (Paliwal, 2006) involving scientific knowledge and expert participation (Paliwal, 2006; Toro et al., 2010; Nita et al., 2022).

The methodology describes first the strategies used to group categories of environmental impacts for EIAs evaluation, followed by a presentation of the study area and eight construction cases scattered across the region. The results section opens with the proposed evaluation matrix and comments, followed by a discussion and conclusions.

2. Methods

During the International Workshop Seminar on Urban Hydrology and Development: Challenges and Opportunities in the Caribbean (Barranquilla) in 2018, a survey was conducted among 45 experts from local authorities and environmental sciences experts from the academic, institutional, and consultative sectors. They were asked: What are the environmental challenges of infrastructure development in the department of Atlántico, Colombia? and What are the main effects of rapid road infrastructure growth in the Colombian Caribbean? In each case, answers included a wide range of problems relating to freshwater ecosystems and ecological connectivity, but large-scale hidden effects were also central. These latter were a set of notions, indications, or concerns about systemic problems or cumulative effects not thoroughly understood due to decades of gradual implementation of road works and poor analysis of the effects on a regional scale.

To offer insights into, confirm or discuss the experts' opinions, the strategy defined was to review the scientific literature and confront identified set of impacts/effects with EIAs of road projects available throughout the region. The identified impacts/effects constitute a vast and varied set. This made a complete analysis or comparison between them and EIAs problematic and an unjustified effort. The strategy adopted was to group impacts/effects and evaluate how EIAs approaches or deal with the resultant grouped categories.

2.1. Identifying roadworks effects in the Caribbean

Environmental impacts/effects were categorized based on a simple association exercise performed within the experts workshop. This produced four categories: hydrological connectivity, surface drainage, underground flow, and ecological/land connectivity. An importance' factor built showed the first and fourth categories to be the most relevant for the participant experts. The same importance was given to a set of poorly defined regional/systemic effects. This last concern was considered an emergent outcome that related to all impacts/effects and was therefore not included as a category in its own right but was incorporated into the analysis's score criteria (See Evaluation Matrix).

By listing and discussing impacts/effects found in the scientific literature, a fifth category was distinguished: landscape fragmentation. A summary of the categories is shown in Fig. 1 and called hereafter "systemic impacts" or "systemic effects" and are explained next.

1. **Hydrological connectivity** groups all those effects resulting from interference in the natural connections between surface water bodies;
2. **Surface drainage** involves all changes in the direction, quantity, or temporality of the natural course of rainwater running on the surface (including temporary or permanent modifications to water course);-
3. **Underground flow or hydraulic conductivity** refers to those effects that relate to the natural flow of groundwater, modification of soil infiltration conditions, aquifers recharge, and exchange with surface water;
4. **Ecological connectivity** means changes in functional or structural aspects of the ecosystem, both freshwater and terrestrial ecosystems; lastly,
5. **Landscape fragmentation** encompasses all changes and outcomes of the establishment of physical barriers in the form of roadworks and also the transformations that an access road allows, such as a natural area becoming an area of agricultural production or tourism on account of ease of transport.

2.2. Evaluation matrix

The five systemic impacts assess each selected case study. Each case was rated against each of the systemic impacts on a scale from one to four. One (1, red) means no considerations of systemic impacts, and four (4, green) means that impacts and management measures consider systemic effects and outline or discuss implications at the regional level. Table 1 shows the details of the evaluation criteria.

We consulted the dossiers available in the online documentation centers of the Caribbean Regional Environmental Authorities, the National Authority for Environmental Licenses (ANLA) and the National Infrastructure Agency (ANI). The selection criteria were: to have been produced in the last five years (to have a uniform regulatory framework); and to contain at least one case from each department in the Colombian Caribbean (to better represent a regional view). A total of eight (8) files of environmental licenses awarded to road projects were selected. The locations and descriptions of the projects considered are provided in Fig. 2 and Table 2 respectively.

These projects encompass the construction of road segments or bypasses between 2015 and 2017 that ranged from 5.3 km to 20.16 km in length. Road projects listed in the table as 1, 2, 3, and 8 are located in marine and coastal or freshwater wetland

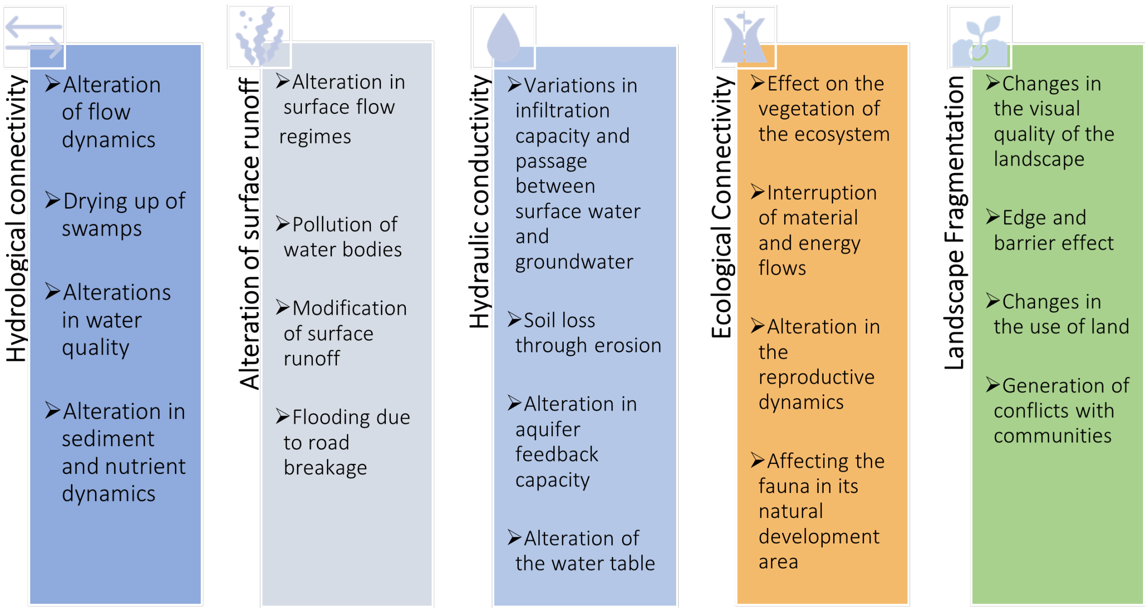

Fig. 1. Systemic Impacts or Effects. Five categories based on experts' survey and literature review. Proposed to assess EIAs
Source: authors

Table 1. Evaluation Criteria

1	Does not list any impact related to the systemic effect.
2	Lists at least one impact related to the systemic effect but fails to outline mitigation measures.
3	Lists impacts related to the systemic effect and outlines mitigation measures for the area of influence of the project. Does not consider effects at the regional scale.
4	Lists impacts related to the systemic effect and outlines mitigation measures for the area of influence of the project. Also considers or discusses effects at the regional scale.

Source: authors

environments. Road projects listed as 4, 5, and 7 are located in tropical dry forest environments, while project 6 fell within both ecosystems.

2.3. Study Area

The Colombian Caribbean is the northernmost natural continental region of Colombia, with a land area of 132,244 km^2 that accounts for 11.6% of Colombian´s continental territory. This research's study area is limited to departments in the Colombian Caribbean region (Fig. 2).

The continental Caribbean plain is dominant in the region and is framed by the Andean Mountain range's foothills to the south and east and the Caribbean Sea to the north and west. The Sierra Nevada de Santa Marta stands out in this region with snow-capped peaks at 5,775 m at less than 50 linear kilometers from the coast. The Caribbean hydrographic region accounts for 82% of swamps nationwide (Meisel-Roca & Pérez-Valbuena, 2008). There are 185 priority areas for the conservation of 24 types of ecosystems, including mangroves, fresh and salt coastal lagoons, marshes, coral

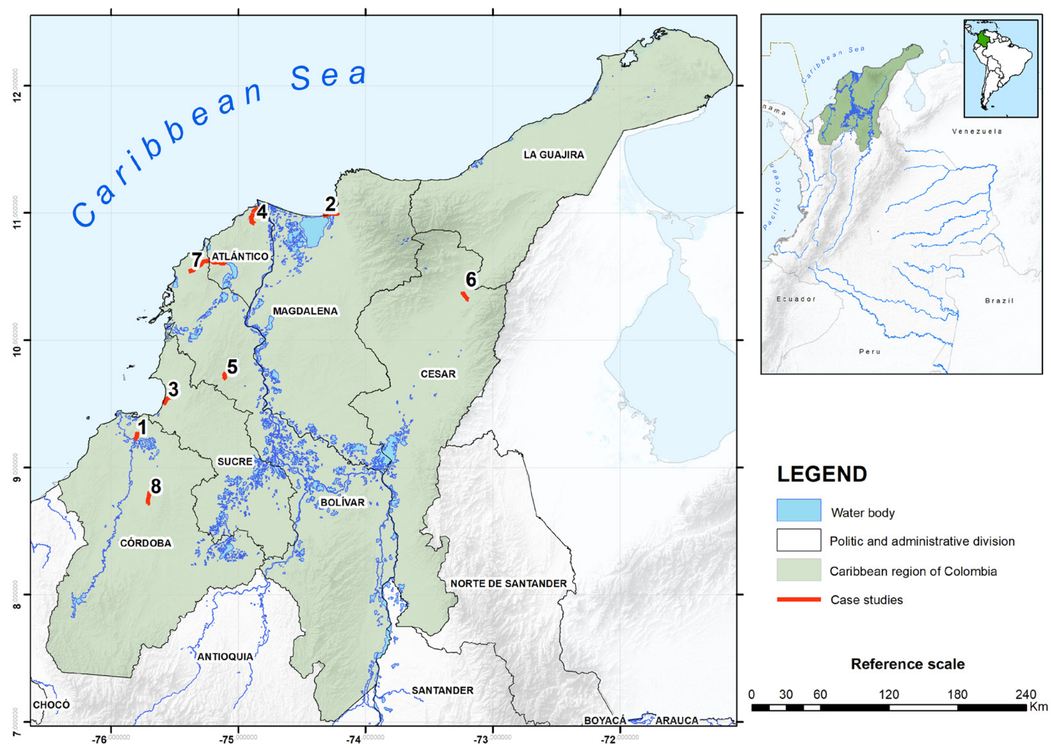

Fig. 2. Caribbean Region of Colombia and localization of analyzed road projects
Source: authors

Table 2. Description of road projects evaluated as case studies in the Caribbean Region

ROAD PROJECT (KEY NAME)	MUNICIPALITY	MAIN ECOLOGICAL STRUCTURE	MAIN IMPACT/ MITIGATION MEASURE
1. RUTA AL MAR SAS. CONCESSION Lorica Bypass **(Lorica Bypass)**	Santa Cruz de Lorica / Córdoba	The dynamic set of plant and animal communities of the Sinu River marsh. (freshwater)	*The most affected component is the **socioeconomic environment.** *In terms of severity, **aquatic ecosystems** are affected.
2. RUTA DEL SOL II CONCESSION - Caribbean highway dual carriageway bypass. **(Ciénaga Caribbean highway bypass)**	Tasajera- Ciénaga/ Magdalena	*Coastal lagoon; coastal marine platform, Ciénaga Grande de Santa Marta, Caribbean Sea. *Low and dense freshwater swamp forest (mangrove)	*Water pollution *Modification of water streams *Change in groundwater availability * Sedimentation-related problems *Changes in plant cover.
3. RUTA AL MAR S.A.S CONCESSION - Section 7.3 Tolú-Pita abajo-El pueblito. **(Tolú - Pita abajo - El Pueblito highway)**	Santiago de Tolú/Sucre	Alluvial-coastal plain of the Gulf of Morrosquillo	*Alteration of plant cover *Wildlife roadkill *Alteration of aquatic and terrestrial ecosystems *Pollution of water bodies *Positive and negative socioeconomic factors
4. CARTAGENA–BARRANQUILLA CIRCUMFERENTIAL HIGHWAY - DE LA PROSPERIDAD - FUNCTIONAL UNIT 6 **(Prosperidad highway)**	Galapa–Barranquilla / Atlántico	**Tropical Dry Forest.** 15.5% of Area on influence comprises a natural cover (mangrove, secondary vegetation, and grassland); the rest are anthropized areas	*Population displacement *Alteration of the ecosystem
5. BYPASS CONSTRUCTION. MUNICIPALITY EL CARMEN DE BOLÍVAR **(Carmen de Bolívar bypass)**	El Carmen de Bolívar / Bolívar	Tropical Dry Forest	*Alteration of habitats ecosystem *Water pollution due to liquid waste
6. CONSTRUCTION OF A NEW TWO-WAY (BYPASS) BETWEEN THE MUNICIPALITY OF SAN DIEGO AND ROAD TO LA PAZ **(San Diego–La Paz bypass)**	San Diego, Valledupar, La Paz / Cesar	**Tropical Dry Forest Ecosystem** — Gallery and riparian forests, open scrub, open sclerophyll scrub, high and low secondary vegetation, sandy areas, rivers, lagoons, lakes, and swamps	*Changes in landscape quality *Modification of wildlife habitats
7. CARIBBEAN ROUTE SECTION 5-6 (**Concession Caribbean section 5-6 highway**)	Sabanalarga, Atlántico	Tropical Dry Forest	*Conflicts with communities *Alteration of sensitive environm. areas
8. RUTA AL MAR S.A.S CONCESSION San Carlos bypass **(San Carlos bypass)**	San Carlos / Córdoba	Marsh Complex (Los Quemados Marsh, Charco Grande Marsh, Martinica Marsh, Larga Marsh) (Areas of ecological relevance)	*Changes in pedestrian and livestock mobility *Population relocation *Alteration of forests

Source: authors

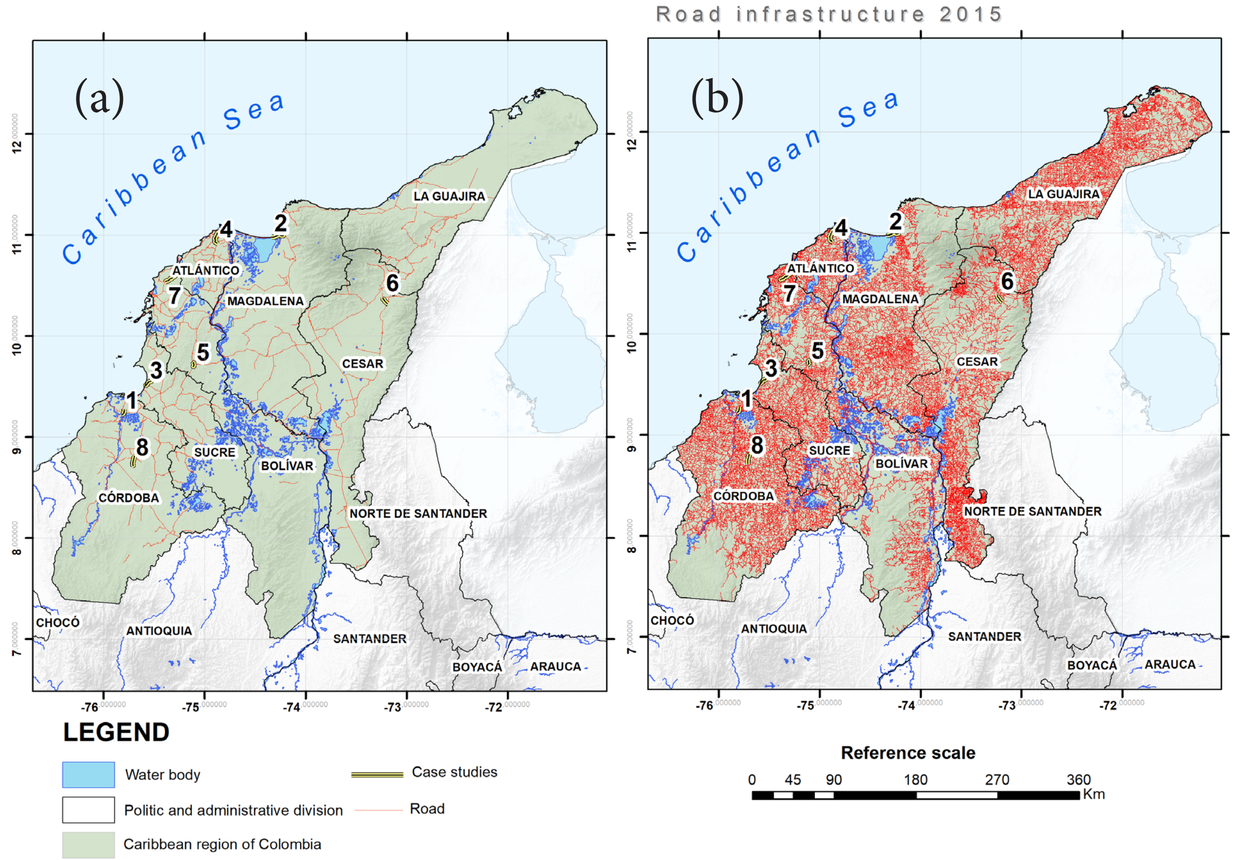

Fig. 3. Road network evolution in the Caribbean; a) the 1970s b) 2015
Source: authors

reefs, seagrass meadows, moors, high-mountain wet forests, freshwater swamp forests, tropical dry forests, and natural and transformed savannas (Aldana-Domínguez, 2014). The ecosystem services directly favor 20.43% (9.86 million inhabitants) of the Colombian population that inhabits this region.

Comparative analysis of roads in 1970 and 2015 from the Human Spatial Footprint study by the Alexander Von Humboldt Institute (Correa Ayram et al., 2020) found that the road density in the 1970s is estimated at 53 m/km^2 – from a total of 7,000 km of roads, as compared to 692 m/km^2 in 2015. This indicates an approximate increase of 1,300% (Fig. 3).

3. Results

The significant impacts and management measures undertaken for each EIA case are presented in Table 2. The features vary from socio-economic impacts, wildlife roadkill, contamination of water bodies, and, most recurring, modifications of plant cover. The results of assessing the road projects' EIAs, in terms of the extent to which they considered the systemic impacts proposed herein, are presented with a visual aid, being color-coded in Table 3. Averages by column show how some systemic effects are considered more than others. The averages by row give an idea of which EIA is closer to the integrality and wideness of the evaluation proposed and synthesized by Table 1.

Hydrological connectivity scored the most on average (3.1/4.0). Cases 4, 5, 6, and 7, with a rating of 3, presented impacts related to this systemic effect, but the measures focus on compensation and mitigation concerning liquid waste, building materials, and drainage structures management. These were tropical dry forest areas without large water bodies. Cases 8 and 2 (located in wetland systems) prioritized measures such as liquid waste management and crossings structures over water bodies. However, no specific mention was made or study done of the impacts on flow dynamics.

Table 3. Assessment of EIAs against systemic effects

	Road Project (Key name)	Hydrological connectivity	Hydraulic conductivity	Alteration of surface runoff	Landscape Fragmentation	Ecological Connectivity	Average
1	Lorica bypass	4	1	3	3	3	**2,8**
2	Ciénaga Caribbean highway bypass	3	2	2	3	2	**2,4**
3	Tolú- Pita Abajo- El pueblito highway.	3	1	2	3	3	**2,4**
4	La Prosperidad highway	3	2	1	3	3	**2,4**
5	Carmen de Bolívar, bypass	3	3	3	3	2	**2,8**
6	San Diego - La Paz, bypass.	3	1	1	3	2	**2**
7	Concession Caribbean section 5-6. highway	3	1	1	2	1	**1,6**
8	San Carlos bypass	3	1	2	3	2	**2,2**
	Averages	**3,1**	**1,5**	**1,9**	**2,9**	**2,3**	

Source: authors

It is expected that altered water flow and current-carried sediments will affect the water balance due to flow dynamics (Keesstra et al., 2018). Changes in the natural water balance and equilibrium are particularly relevant in such cases (Golden et al., 2014; Jaramillo et al., 2018; Raiter et al., 2018). One of the main consequences in these systems can be the subsequent modification of sediment dynamics and changes in the landscape (Bracken et al., 2013), and wetlands desiccation (Saaltink et al., 2018).

In cases 2 and 3, despite these projects being located in areas rich in water bodies, the efforts provided therein aim at minor drainage works for the currents to pass from one side to another, without further analyzing impacts on a larger scale. Specifically, case 2 mentions the use of sediment containment barriers, awning fences or plant covers, protection barriers for water bodies during the construction of piles of the viaduct, given the history of the sediment that the Magdalena River drags to its outlets. Furthermore, therein are listed energy dissipation works and lateral protection walls (gabion walls) that prevent subsidence in the banks.

The systemic effect rated the lowest (1.5/4.0) was **Hydraulic conductivity,** which involves exchanges with groundwater or the flow dynamics connections and transfers of underground flows through a porous medium. The Environmental Management Guidelines for Road Infrastructure Projects (EMGRIP) (INVIAS, 2011) forbid the dumping of roadwork water in rivers and aquifers headwaters and encourage measures to protect wells or reservoirs from pollution and groundwater quality monitoring. This systemic effect was rated poorly in the case studies, since the corresponding management measures are unclear regarding maintaining infiltration capacity. Case 5 is located in a tropical dry forest ecosystem and has a weighting of 3, and management measures are associated with mitigating alterations of aquifers' quality. Despite the little attention to this systemic impact, frequent changes in soil use, compaction, or waterproofing may modify underground runoff and infiltration patterns, while exchanges with surface water, pollution, and water quality and soil erosion do not go unaltered (Thompson et al., 2008).

The third studied systemic impact in the case studies, **Superficial runoff**, was somewhat related to soil use changes. The changes in surface runoff will consequently alter flow patterns and natural water balance by reducing infiltration (Bunn & Arthington, 2002). Only two projects – 1 and 5 – provided some management measures for this type of alteration, hence their weighting of 3. These are hydraulic drainage works for conducting rainwater and preventing the dragging of particulate matter to water bodies. The EMGRIP and the Drainage Manual for Roads (INVIAS, 2009) promote using drainage and underdrainage works so that the road's operation is unaffected and sediments are withheld in the underdrainage. However, changes in flow and sediments dynamics can modify on-site moisture patterns. Consequently, roads divert and concentrate natural flows, driving new canal formations (Raiter et al., 2018). Projects 2, 3 and 8 only listed measures to avoid water source contamination and drainage management to avoid setbacks in the construction stage. The remaining, lower-rated projects did not account for impacts to surface runoff.

The **Landscape fragmentation** is a second-rank category according to the evaluation method. The EMGRIP sets out specific mitigation measures relating to revegetation and meadowing in cases where the landscape quality can be affected. The analyzed studies, in all cases, address landscape recovery measures through revegetation. Concerning cases 1, 2, 3, and 8, located in marine and coastal wetland and freshwater environments, alterations to landscaping visual quality were accounted for, but no specific measures to mitigate that effect were proposed. Landscape fragmentation seeks to characterize a territory's environmental state based on an analysis of its subdivisions (Mancebo Quintana et al., 2010; MARM, 2010). However, the edge or barrier effect impacts considered by the analyzed EIAs, accounts mainly for threats to fauna due to roadworks, and compensation measures are in the form of signage and socialization with the community with regard to the animals on the road.

The last evaluation comprises all direct and indirect impacts related to **ecosystem connectivity**. In terrestrial ecosystems, the effects or impacts are in the form of disruptions to nutrient, energy, or genetic information flows, the removal of plant cover, and habitat destruction (Saunders et al., 1991). Modification of flow dynamics or water balance in freshwater ecosystems also alters sediment dragging and water quality in terms of salinization (Entrekin et al., 2019) and dissolved oxygen. The EMGRIP proposes mitigation in the form of biological corridors that allow organisms to roam freely and permit continuity of some energy flows. Cases 3, 4, and 5 listed impacts on the functionality of the ecosystem itself and proposed identifying and enclosing natural fauna corridors, signage for wildlife crossing areas, and community awareness as mitigation measures. Case 1 accounts for the effects on terrestrial and aquatic ecosystems. Establishes, as mitigation measures, revegetation activities, and minor works to ensure the marshes' natural water flow, bearing in mind that these alterations would reach other areas of the Bajo Sinú marsh. Lastly, the projects in cases 2, 6 and 8 altered the ecosystem's functionality, or the habitat itself, and provided no specific measures.

4. Discussion

4.1. Standard and outdated management measures

The hydrological connectivity systemic impacts were rated the highest. However, this does not mean that each project performed a thorough study and established appropriate management measures to address alterations in water connectivity dynamics and their consequences. In general, the EIAs failed to develop integrated analyses or complex models for all the systemic impacts on the environment. On the contrary, although each EIA deals with different environments, here is an observable simplification of the impacts identification process. In the line pointed out by Nita and collaborators (2022), we found that the management measures look repetitive and preset, resulting in typified or *pro-forma* EIAs that only cover minimal legal requirements.

Regarding water systems (surface or groundwater), the regulations focus on measures to prevent contamination of water bodies and to maintain drainage in terms of water volume, and on changes in the terrain's morphology. The EIAs' control measures are reduced to preventing dumping, monitoring water quality and constructing drainage structures such as sewers, gutters, and box culverts, the objective of which is the effective evacuation of rainwater or runoff to avoid damage to the roadworks. Such an approach ignores the need to understand water bodies' connectivity dynamics and their intricate spatial and temporal variability patterns (Bracken et al., 2013; Freeman et al., 2007), triggering damage to the water balance. Another consequence of altered flow dynamics that is unaddressed by EIAs is the modification of the transport of matter, energy, and organisms inside or between water bodies, indirectly affecting the health of ecosystems (Freeman et al., 2007), water quality parameters (Thompson et al., 2008) and sediment dragging dynamics.

Concerning the systemic effects of territory fragmentation and ecosystem connectivity, the EIAs frequently dealt with impacts in the form of landscape changes, land-use change, plant cover removal, and erosion. The management actions propose revegetation with native species, signage for wildlife corridors, and species relocation, but the fragmentation phenomenon itself is yet to be addressed. The EIAs did not analyze its systemic consequences; nor did they employ the metrics commonly referred to in the scientific literature as fragmentation indicators. These indicators evaluate habitat dynamics and local ecosystem processes, facilitating loss of territorial connectivity monitoring in habitats at various scales (MARM, 2010). Similar to freshwater ecosystems, barrier-effect territorial discontinuities alter natural material, energy, and information flow in the territory, which are the basis of system development and richness (Cardona-Almeida et al., 2019) affecting biodiversity and ecological redundancy (Jørgensen, 2012). Only projects 1 and 3 observed safe fauna passes through water-drainage box culverts. This calls attention to how all the projects, located in rural areas, failed to implement more robust measures despite documented evidence that vouches for ecologic corridors as a management strategy due to their abilities to restore biodiversity and keep the ecosystem resilience (Karlson et al., 2016; Dos Santos et al., 2020).

4.2. The regional scale

Of the eight studies, only case 1 (Lorica bypass) warned about adverse effects on currents' dynamics and its communication with the marshes that characterize that territory. Those water bodies fall out of the EIAs' area of influence, which is why it was rated four (4) in the systemic impacts assessment matrix. However, profound effects on water dynamics at the regional scale were not analyzed. Concerning freshwater ecosystems, alteration of currents and flows entails large-scale ecological effects. For terrestrial ecosystems, progressive fragmentation generates large-scale effects that cause landscape changes and reduce habitats and biodiversity (Saunders et al., 1999; Gurrutxaga, 2011). Even so, all projects failed to list possible external impacts or effects from the influence area, ignoring the terrestrial and water ecosystems' systemic and interdependent nature.

Figure 4a provides a notion of the problem, the linear distance between projects 1 and 8 is approximately 40 km. Surrounded by a complex marsh and river system, the maximum width of the area of influence is about 5 km. Beyond any criticism of the delineation of the area of influence, local changes can affect larger areas through synergism and residual effects. In addition, monitoring strategies or activities defined by EIAs to be carried out while the road is operational focus mainly on the verification of management measures but not on the system processes or functionalities that would develop an understanding of the possible problems at the regional or landscape level.

4.3. Cumulative effects

Although each project's EIA's area of influence complies with the regulations' provisions, limited attention to spatial analysis might hide accumulated effects or cause the overlapping thereof both in space and time. So, limiting themselves to minimal requirements, project managers will not be willing to study these consequences, and local environmental authorities will be oblivious to them as well. Figure 4 zooms in on the two southernmost projects, where the cumulative effect for the region can be illustrated by the contrast between Fig. 4a (1970s road infrastructure) and 4b (2015 road infrastructure). That image attests to how territory and ecosystems become fractured as time passes and alert us to the accumulation and magnification of effects.

Numerous projects were executed in various years that gradually built small segments of the network using different executors, authorities and regulatory frameworks. These frameworks went from having an absence of environmental considerations before Law 99 of the year 1993 to containing environmental licensing processes with several subsequent modifications influenced by national policy priorities for infrastructure development.

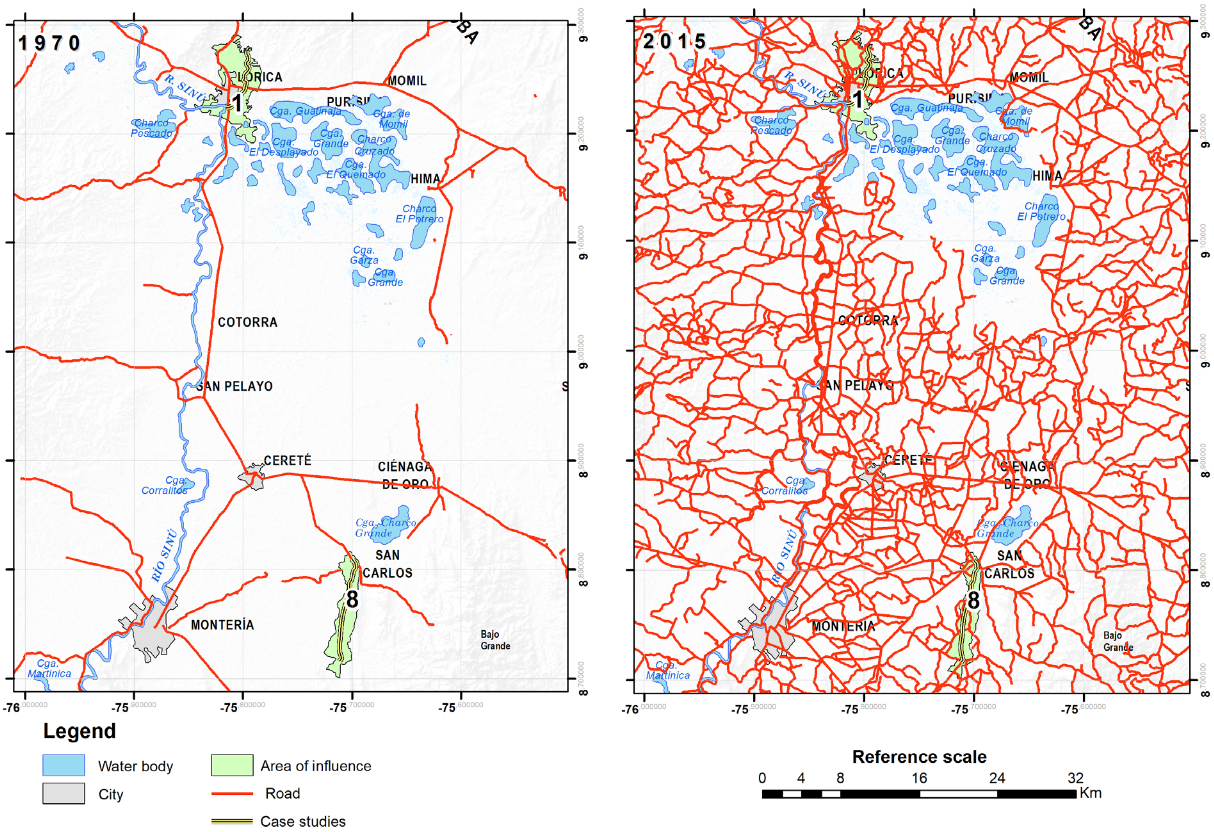

Fig. 4. EIAs' area of influence (1 and 8) and development of road infrastructure. a) 1970s road network, b) 2015 road network
Source: authors

The analyzed projects failed to list or consider the effects or mitigation action of any other nearby project. Nor are there recommendations or analyses on possible future projects or road-related implications for the surrounding system's future development. All the EIAs analyzed describe scenarios with and without the project; however, none evaluated the environmental or ecological impacts once the work was completed. Only two studies (1 and 8) considered effects during the operational phase, i.e., during the useful life of the road. However, those effects focus on socio-economic matters such as commercial activities, the impacts of noise, and effects on ways of life. The EIAs studied here analyzed the impacts of the construction stage associated with civil works processes and failed to regard those related to the presence of infrastructure in a natural environment.

4.4. Limitations

Even though hydrological connectivity was rated highly, the EIAs show a stronger focus on the compensation of terrestrial ecosystems and measures such as revegetation, attaching little importance to impacts on water systems dynamics and freshwater ecosystems. That high rating is linked to abundantly implemented measures related to sewers and water quality monitoring rather than to the analysis or management of systemic problems

That constitutes a limitation of the proposed method, based on the grouping of five categories of impacts/effects, that responds to the expressed concern of local experts. It allows direct comparison with the management tools in question. However, given the large number and variety of effects/impacts in each category, the grouping may, for high ratings, mask the detail of which measures or analyses are being considered. However, it does give a good account of which categories receive less attention, such as hydraulic conductivity. The evaluation matrix score evidenced one of the initial concerns placed in the hypothesis, namely that there is little connection between EIAs (i.e., they do not relate to or take into account considerations or recommendations from one another) and that they contain little spatial context. Even if the small number of projects considered does not allow absolute conclusions to be drawn, the assessment matrix presented is helpful for global comparisons and easily replicable with the same or new categories depending on the context.

5. Conclusions

Road infrastructure has grown significantly in the Colombian Caribbean and, according to local experts, environmental impacts are not well-understood or -managed. The ecosystem's diversity and the economic development dynamics of the region makes it susceptible to ecological catastrophes – which have already occurred. Identifying gaps between current management strategies and scientific knowledge is vital to improve regional road planning and environmental management.

With the evaluation of eight EIAs distributed throughout the region, we expect to offer clues to reveal whether experts' concerns are sound or not, and where to focus for future studies. In the scope of this study, we confirmed the proposed hypothesis. So, EIAs do not describe the wide range of environmental effects identified by the scientific literature.

Each EIA failed to address systemic effects in depth. There were no complex analysis tools such as models or integrated analysis, but, rather, a series of almost-standardized management measures is implemented. The projects analyzed are limited to a very narrow area of influence and focused on the construction stage. Consequently, they do not consider regional effects or impacts such as those related to spatial connectivity of ecosystems, hydro systems, and territory functional processes. Furthermore, the EIAs analyzed did not consider other nearby or previous road projects' considerations or management strategies. It is foreseeable that the overlapping of these road projects brings cumulative effects outside the areas of influence, both spatially and over time, and current environmental management tools are incapable of noticing or estimating them.

It is worthwhile to develop studies on water connectivity, ecological connectivity, and territory fragmentation at the regional level before and during the development of road projects that will serve as the planning basis for future projects. It is not clear what the cumulative effects on Caribbean ecosystems of road infrastructure are, so it is advisable to propose studies that identify impacts and restore ecosystem services in the region.

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