Analysis of the environmental licensing procedure for coastal environments in Colombia: A Geomorphological perspective from the concept of susceptibility to the effect of human interventions

Análisis del procedimiento de licenciamiento ambiental para entornos costeros en Colombia: una perspectiva geomorfológica desde el concepto de susceptibilidad al efecto de intervenciones humanas

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To the light of my life and the color of my days,

my little heaven and my family …

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List of Acronyms and Abbreviations

AHA	High-density settlements
AHB	Low-density settlements
AHM	Luxury settlement with pier
AHP	Palatial settlements
AHU	Luxury settlements
ANLA	Autoridad Nacional de Licencias Ambientales (national authority of environmental licensing)
BBD	Beach & Bare Dunes
BCT	Beach & Cliff/Terrace
BFP	Beach & Floodplain
BLS	Beach & Lagoon/Swamps
BNS	Beach nourishment
BSP	Basic sanitation pipes
BVD	Beach & Vegetated Dunes
BVF	Beach & Vegetated Floodplain
BVL	Beach & Vegetated Lagoon/Swamps
CAP	Roads, double roads, bridges…; Tunnels; Airports and runways
CCCC	Continental Caribbean Coast of Colombia
CFP	Conduction of fluids through pipelines
CIOH	Centro de Investigaciones Oceanográficas e Hidrográficas del Caribe (research institute of the maritime authority)
CTN	Cliff/Terrace of Non-resistant rock
CTR	Cliff/Terrace of resistant rock
CYP	Groins
DAR	Darien
DIMAR	Dirección General Marítima (maritime authority)
DMI	Mining
DSP	Desalination plants
ECU	Environmental Coastal Unit
EDF	Sun, Sea and Sand Tourism
EDM	Sun, Sea and Sand tourism with pier
EDN	Nature Tourism
EEH	Exploration/extraction of hydrocarbons
EIA	Environmental Impact Assessment
EIS	Environmental Impact Study or Statement
ELF	Electric lines and facilities
ELP	Environmental Licensing Procedure
EMP	Inlet navigation channels
ESH	Historic structures

FFF	Fishing
GMR	Mariculture
GRA	Aquaculture
GST	Geological storage
GTP	Geothermal plants
GUA	Guajira
HAB	Hard Bottoms with Active Biogenic Coverage
HBO	Hard Bottoms of Biogenic Origin
HBR	Hard Bottoms of Bare Rock
HUMBOLDT	Instituto de Investigación de Recursos Biológicos "Alexander von Humboldt" (research institute of biological resources)
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales (institute of hydrology, meteorology and environmental studies)
IDO	Irrigation districts
IFC	Installations in fluvial causes
IIAP	Instituto de Investigación Ambiental del Pacífico "John Von Neumann" (research institute in the Pacific region)
INA	Naval military installations
INVEMAR	Instituto de Investigaciones Marinas y Costeras "José Benito Vives de Andréis" (national research institute of marine and coastal areas)
LUC	Changes in land use (deforestation)
MAG	Magdalena-Canal del Dique and Ciénaga
MAGDIQUE	Magdalena River - Canal del Dique complex - Cienaga Grande de Santa Marta lagoon system
MAN	Manufacture
MBX	Muddy Bottoms
MCR	Cruise tourism
MDS	Marine dredging
MIL	Military installations on land
MMN	Marinas
MOC	Modification of channels
MUP	Public docks
MUR	Sea walls, walks and ridges
NAV	Internal Maritime Transport
NBX	Naked beach
POMCA	Plan de Ordenamiento y Manejo de una Cuenca (watershed management plans)
POMIUAC	Plan de Ordenamiento y Manejo Integrado de una Unidad Ambiental Costera (environmental plans for coastal zones)
POT	Plan de Ordenamiento Territorial (land use plan)
PUC	Deep water ports without shelter
PUG	Shallow water ports without shelter
PYC	Walks and ridges
RDS	River dredging
RLM	River/Lagoon mouth

ROB	Rocky Offshore Bars
ROP	Breakwaters and artificial reefs
SBV	Sandy Bottoms with Biogenic Coverage
SBX	Sandy Bottoms
SEA	Stretegic Environmental Assessment
SEP	Solar energy plants
SGC	Servicio Geológico Colombiano (georolical service of Colombia)
SIMCHI	Instituto Amazónico de Investigación Científica (research institute in the Amazon region)
SIN	Sinú and Morrosquillo Gulf
SINA	Sistema Nacional Ambiental (national environmental system)
SME	Submarine emissary
SMR	Northern slope of Sierra Nevada de Santa Marta
SOB	Sandy Offshore Bars
SPS	Sheltered ports
SWD	Solid waste exploitation and disposal
TEI	Total Environmental Impact
ToR	Terms of Reference
TPC	Thematic parks and camping
TSF	Transformation/storage of fossil fuel
TYS	Thermoelectric plants
UAG	Livestock, farming and golf course
UEI	Unitary Environmental Impact
UGM	Underground water movement
VFE	Railways and facilities
VFE	Railway infrastructure
WPP	Wind power plants
WTP	Wastewater treatment plants

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ABSTRACT

Important flaws in the environmental licensing procedures in Colombia are directly related to the generalized degradation of its coastal fringes and littoral zones. These areas are severely affected by human interventions that interfere with natural processes and severely modify their sedimentary balances, geomorphological contexts, and physical-biotic conditions. Among many other examples, the following stand out: a) the widespread erosion and destruction of beaches and dunes in the Magdalena River delta, associated with the construction of the Bocas de Ceniza jetties; b) the drastic modification of the hydrodynamics of the littorals at the Atlantic and Magdalena departments due to linear infrastructure projects; c) the hyper-salinization and loss of more than 30,000 hectares of mangrove in the lagoon complex of the Ciénaga Grande de Santa Marta (CGSM) due to the expansion of the agricultural frontier and linear infrastructure projects; d) the accelerated retreat of beaches and cliffs in the southern Caribbean, due to activities such as deforestation, beach material extraction, and disordered and chaotic construction of nearly 500 rigid shore protection works; and e) the salinization of more than 10,000 hectares of freshwater marshes in the Bay of Cispatá as a consequence of the induced formation of the new delta of Tinajones.

In this sense, the location of infrastructure in geological and geomorphologically unstable lands, affected by phenomena such as coastal subsidence and mud diapirism, poses first order natural threats and risks. This is a palpable panorama in the present and future of urban and rural areas of cities such as Barranquilla, Cartagena, Arboletes and Necoclí, all of them with future developments (industry, ports, urban development) of the greatest importance. The environmental costs associated with such interventions are incalculable, not counting the existence of numerous other examples, which demonstrate among other factors an insufficient acknowledgment to geomorphology in the evaluation, monitoring, and control of human interventions in the marine-coastal environment. These environmental management functions in Colombia are provided through the environmental licensing procedure, which rests upon national and regional authorities according to Law 99 of 1993. In the above context, the following research questions arise:

- ➔ What elements of the environmental licensing of interventions in coastal environments can be improved, giving priority to the particular geomorphological contexts of the intervention zones?
- ➔ How has the regulatory system evolved in Colombia with respect to human interventions on coastal environments?
- ➔ What technical improvements can be made to the Colombian regulatory framework to guide the evaluation, monitoring, and control of human interventions from the geomorphological approach of *susceptibility*?

This research work examines the environmental regulatory framework that currently governs Colombian coastal zones, through two geographic levels. At the first macro level, human interventions

are characterized and analyzed on the continental Caribbean coast, a region that represents a significant sample of the Colombian context due to its higher levels of human occupation and consequent anthropogenic disturbances. At a second level, in greater detail, the conceptual and methodological approach resulting from this research is defined and illustrated, with the demonstration in one of the coastal environmental units defined by decree 1120 of 2013 for integrated coastal management.

To answer the questions raised, **Chapter I** briefly *introduces the historical geomorphological evolution of the Colombian coastlines since the end of the XVIII century*. The complex geology and geomorphology of the Caribbean and Pacific coasts of Colombia are evident in this "appetizer", in which low-relief deltaic islands and mangroves contrast with steep rocky reliefs, cliffs and wide emerged and submerged coastal platforms. The historical evolution of the Colombian littorals involves changes in the coastline estimated in hundreds of meters, at maximum rates of 40 meters a year (Punta Rey, Arboletes, Tumaco Bay), and land losses and gains of the order of tens of square kilometers (Ciénaga de Mallorquín, Isla Cascajo, Tinajorenas Delta - Cispatá, Bay, Urabá Gulf, San Juan and Patía river deltas). These cases reflect drastic variations in the sediment balances of the coast, many of them caused or heavily influenced by human actions, such as navigation infrastructure, modification of river courses and coastal protection works.

Chapter II *identifies the geomorphological perspective in the environmental licensing of coastal interventions in Colombia, based on its comparison with the regulatory frameworks of Italy, Spain, and Cuba*. The interviews and documentary reviews highlighted 59 interventions associated with human uses and activities in the coastal zones, whose compulsory nature for the licensing varies among countries. The natural geomorphological processes were also analyzed within the technical criteria included in the official guidelines for environmental studies. It is concluded that, despite the worldwide acceptance of environmental impact assessments through a licensing procedure, their application in coastal environments is still very diverse and limited in terms of the pertinence of the geomorphological processes that configures the coast. Therefore, seven good practices for the evaluation and control of anthropogenic impacts in the coastal zone are underlined, and a new process-oriented approach is introduced for environmental licensing procedures.

In **Chapter III**, an inventory and *characterization of human interventions on the continental coast of the Colombian Caribbean are documented, to establish a regional baseline*. Based on images from Google Earth, a total of 2,742 works and activities were located, representing 29 different types of human interventions. This inventory was complemented with an evaluation of the general impact of each intervention, based on four attributes of its geomorphological effects, namely, extension, intensity, reversibility, and persistence. The three most common types of human interventions (low-density settlements, groins and luxury settlements with dock) were also the ones with the higher environmental impact. However, some interventions (e.g., high-density settlements or road infrastructure) had higher environmental impact values than more frequent ones.

Based on this exhaustive analysis of the Colombian Caribbean, **Chapter IV** *evaluates the national environmental regulatory framework applicable to coastal areas*. It evidences that the licensing procedure in Colombia currently regulates only four of the ten types of interventions with greater effect in the Colombian coastal zones. Also, the number of works and activities covered in each new legislative reform consistently decreased over time. In addition, three policy implications were extracted for coastal and ocean planning, related to a) the geographic diversity of tropical coastal zones; b) the need for territorial carrying capacity instruments and; c) the lack of articulation of territorial planning instruments. The conclusions identify an important gap between technical and political decision making in the environmental regulatory framework of Colombia, which stresses the need for the design of novel methods to assess the breadth and length of geomorphological dynamics in an environmental management context.

Therefore, the previous chapters highlight three important deficiencies in Colombia, with respect to the environmental management of human interventions in coastal areas: 1) the absence of a strategy to determine interventions that require an environmental licensing procedure (screening); 2) a poor definition of the scope of environmental studies through relevant information requirements (scoping) and; 3) the disarticulation of environmental management instruments, such as territorial planning and environmental licenses. All these elements ratify that the environmental regulatory framework in Colombia has been insufficient to date to manage the anthropogenic impact in coastal environments due to the unawareness of the natural susceptibility to the effect of human interventions. In this work, the susceptibility is defined as the predisposition of an environmental unit (socio-natural system) to experience changes or affectation due to the introduction of human interventions.

In order to propose improvements to the Colombian environmental system, **Chapter V** *establishes a new conceptual and methodological approach to guide the evaluation, monitoring, and control of human impacts from a geomorphological perspective*. This novel product has been called *Susceptibility to Human Interventions for Environmental Licensing Purposes* (SHIELP). The architecture of this model has three components, which are particular to a kind of environment, namely, geomorphological processes, geomorphological configurations and potentially impacting human interventions. Each of these components is translated into a variable by means of expert qualifications along with a fuzzy logic computation strategy. Therefore, the expert-diffuse system SHIELP qualifies the susceptibility of a distinctive landform to the effects of a characteristic type of human intervention, through the estimated perturbation in each geomorphological process that configures the kind of environment under study. As a demonstration, this chapter also documents the design of the expert-diffuse system for coastal environments, drafted from research workshops with members of the marine and coastal research institute INVEMAR (In Spanish: Instituto de Investigaciones Marinas y Costeras "José Benito Vives de Andréis"). The role of this institute as an official adviser to the environmental authorities in matters of impact assessment demonstrates its relevance to support the expert-knowledge base of the model.

As a consequence, the SHIELP model was applied with the parameters established for coastal environments, resulting in a database of susceptibility values for 4,524 interactions (littoral configuration vs intervention). The real applicability of this exercise corresponds to the translation of this database into a technical criterion to improve the Colombian regulatory framework. On the one hand, five susceptibility ranges were linked to five differentiated instruments, two of which articulate environmental licensing with territorial plans, while the others differentiate the pertinent degree of licensing for human interventions according to location properties (screening). On the other hand, the differentiated instruments were also combined with four degrees of information requirements for the definition of the scope in the respective environmental studies (scoping). In this way, the susceptibility value of a given intervention in a given configuration (interaction) would fit a percentile range that places its environmental control in a territorial competence (regional or national), and through a specific licensing instrument, with differentiated information requirements for the baseline definition.

Finally, the operation of the SHIELP model was also demonstrated with a case study: the environmental coastal unit Magdalena River - Canal del Dique complex - Ciénaga Grande de Santa Marta lagoon system. The geographic information of this regional coastal unit was interpreted according to the parameters defined in the SHIELP model for coastal environments. 154 polygons were delimited in the study area, according to the 40 coastal configurations identified. As a result, 13 cartographic maps represent this area, with the levels of susceptibility attributed to each configuration for the 52 potentially impacting interventions. In order to illustrate the applicability of the model, four scenarios are presented to discriminate interventions by environmental management instrument (screening) and to define information requirements on geomorphological processes (scoping). In this way, the SHIELP model specifies the environmental licensing instrument for human interventions and the corresponding scope of the technical study, given the characteristics of its interaction with the geomorphological configuration.

The **Overall Conclusions** document reflections and recommendations to the Colombian national environmental system – SINA (in Spanish: Sistema Nacional Ambiental) to implement the results of this research. In addition, this work opens a broad perspective for future research in the approach of susceptibility to the effect of human interventions. The SHIELP model for coastal environments can be replicated in different geographies to progressively articulate a national database of coastal susceptibility. Also, the presented methodological scheme can be applied in different kinds of environments, other than the coastal zone. The extension of this approach of geomorphological susceptibility to the variety of tropical ecosystems would set the path for a successful transition from the current anthropocentric and fragmentation-oriented conception towards an ecosystem-based management approach.

RESUMEN

Importantes falencias en los procedimientos de licenciamiento ambiental en Colombia se relacionan directamente con la degradación generalizada de sus franjas costeras y zonas litorales. Estas áreas se encuentran afectadas severamente por intervenciones humanas que interfieren con los procesos naturales y modifican sustancialmente sus balances sedimentarios, contextos geomorfológicos y condiciones físico-bióticas. Entre muchos otros ejemplos, se destacan: a) La erosión generalizada y la destrucción de playas y dunas en el delta del Río Magdalena, asociadas a la construcción de los tajamares de Bocas de Ceniza; b) La modificación drástica de la hidrodinámica de los litorales de los departamentos del Atlántico y Magdalena por proyectos de infraestructura lineal; c) la híper-salinización y pérdida de más de 30,000 hectáreas de manglar en el complejo lagunar de la Ciénaga Grande de Santa Marta (CGSM) debido a la expansión de la frontera agrícola e infraestructura lineal d) el retroceso acelerado de playas y acantilados en el Caribe sur, debido a actividades como la deforestación, extracción de materiales de playa y construcción desordenada y caótica de cerca de 500 obras de defensa costera; y e) La salinización de más de 10,000 hectáreas de pantanos de agua dulce en la Bahía de Cispatá, como consecuencia de la formación inducida del nuevo delta de Tinajones.

En este sentido, la ubicación de infraestructura en terrenos geológica y geomorfológicamente inestables, afectados por fenómenos como la subsidencia costera y el diapirismo de lodos, plantea amenazas y riesgos naturales de primer orden. Este es un panorama palpable en el presente y futuro de zonas urbanas y rurales de ciudades como Barranquilla, Cartagena, Arboletes y Necoclí, todas ellas con desarrollos futuros (industria, puertos, urbanísticos) de la mayor importancia. Los costos ambientales asociados a intervenciones como las mencionadas son incalculables, sin contar la existencia de otros numerosos ejemplos, que evidencian entre otros factores un insuficiente reconocimiento a la geomofología en la evaluación, seguimiento y control de las intervenciones humanas en el entorno marino-costero. Estas funciones de manejo ambiental en Colombia se surten por medio del procedimiento de licenciamiento ambiental, que están a cargo de autoridades de orden nacional y regional según la Ley 99 de 1993. En el contexto anterior, se plantean las siguientes preguntas de investigación:

- ¿Qué elementos del licenciamiento ambiental de intervenciones en ambientes costeros pueden mejorarse, dando prioridad a los contextos geomorfológicos particulares de las zonas de intervención?
- ¿Cómo ha evolucionado el sistema regulatorio en Colombia con respecto a las intervenciones humanas sobre los ambientes costeros?

- ¿Qué mejoras técnicas se pueden hacer al marco regulatorio colombiano para guiar la evaluación, seguimiento y control de intervenciones humanas desde el enfoque geomorfológico de *susceptibilidad*?

Este trabajo examina el marco regulatorio ambiental que actualmente rige en las zonas costeras colombianas, a través de dos niveles geográficos. En un primer nivel macro se caracterizan y analizan las intervenciones humanas en el litoral Caribe continental, región que representa una muestra significativa del contexto colombiano por sus mayores niveles de ocupación humana y consecuentes perturbaciones antropogénicas. En un segundo nivel, de mayor detalle, se define e ilustra el enfoque conceptual y metodológico que resulta de esta investigación, con la demostración en una de las unidades ambientales costeras definidas por el decreto 1120 de 2013 para el manejo costero integrado.

Para responder a los interrogantes planteados, el **Capítulo I** *introduce brevemente la evolución geomorfológica histórica de los litorales colombianos desde finales del siglo XVIII*. En este "abrebocas" se evidencia la compleja geología y geomorfología de las costas Caribe y Pacífico de Colombia, en las cuales islas-barrera deltaicas de bajo relieve y manglares contrastan con relieves rocosos escarpados, acantilados y amplias plataformas costeras emergidas y sumergidas. La evolución histórica de los litorales colombianos involucra cambios en la línea de costa estimados en cientos de metros, a tasas máximas de 40 metros al año (Punta Rey, Arboletes, Bahía de Tumaco), y pérdidas y ganancias de terrenos del orden de decenas de kilómetros cuadrados (Ciénaga de Mallorquín, Isla Cascajo, Delta de Tinajones-Bahía de Cispatá, Golfo de Urabá, Delta de los ríos San Juan y Patía). Estos casos reflejan variaciones drásticas en los balances de sedimentos del litoral, muchos de ellos provocados o influenciados por acciones humanas, como infraestructura para la navegación, modificación de cauces y obras de protección costera.

El **Capítulo II** *identifica la perspectiva geomorfológica en el licenciamiento ambiental de intervenciones costeras en Colombia, a partir de su comparación con los marcos regulatorios de Italia, España y Cuba*. Las entrevistas y revisiones documentales destacaron 59 intervenciones asociadas con usos y actividades humanas en las zonas costeras, cuya obligatoriedad para el licenciamiento varía entre países. Los procesos geomorfológicos naturales también fueron analizados dentro de los criterios técnicos incluidos en las directrices oficiales para estudios ambientales. Se concluye que, a pesar de la aceptación mundial de las evaluaciones de impacto ambiental como procedimiento de licenciamiento, su aplicación es aún muy diversa y limitada en cuanto a la pertinencia de los procesos geomorfológicos costeros. Por consiguiente, se identifican siete buenas prácticas para la evaluación y el control de los impactos antropogénicos en la zona costera y se introduce un nuevo enfoque, orientado en procesos, para los procedimientos de licenciamiento ambiental.

En el **Capítulo III** se hace un inventario y *se caracterizan las intervenciones humanas sobre la costa continental del Caribe colombiano, para establecer una línea base regional*. A partir de imágenes de Google Earth, se ubicaron un total de 2,742 obras y actividades, que representan 29 tipos diferentes de intervenciones humanas. Este inventario se complementó con una evaluación del impacto general de cada intervención, en función de cuatro atributos de sus efectos geomorfológicos, a saber, extensión, intensidad, reversibilidad y persistencia. Los tres tipos de intervenciones humana más comunes (asentamientos de baja densidad, espolones y asentamientos de lujo con muelle) fueron también los más impactantes. Sin embargo, algunas intervenciones (por ejemplo, asentamientos de alta densidad o infraestructura vial) tuvieron valores de impacto ambiental más altos que otras más frecuentes.

A partir de este análisis exhaustivo del Caribe colombiano, en el **Capítulo IV** se *evalúa el marco regulatorio ambiental nacional aplicable a las áreas costeras*. Se evidencia que el procedimiento de licenciamiento en Colombia actualmente solo regula cuatro de los diez tipos de intervenciones con mayor efecto en las zonas costeras colombianas. También se resalta que el número de obras y actividades cubiertas en cada nueva reforma legislativa disminuyó constantemente con el tiempo. Adicionalmente, se extrajeron tres implicaciones políticas para la planificación costera y oceánica, relacionadas con: a) la diversidad geográfica de las zonas costeras tropicales; b) la necesidad de instrumentos de capacidad de carga territorial; y c) la falta de articulación de los instrumentos de planificación territorial. Las conclusiones identifican una brecha importante entre la toma de decisiones técnicas y políticas en el marco regulatorio ambiental de Colombia, lo que subraya la necesidad de diseñar nuevos métodos para evaluar la amplitud y la dimensión de la dinámica geomorfológica en un contexto de manejo ambiental.

Por consiguiente, los capítulos anteriores resaltan tres deficiencias importantes en Colombia, con respecto al manejo ambiental de intervenciones humanas en zonas costeras: 1) la ausencia de una estrategia para determinar intervenciones que requieren un procedimiento de licencia ambiental (screening); 2) una deficiente definición del alcance de los estudios ambientales a través de requisitos de información pertinentes (scoping); y 3) la desarticulación de los instrumentos de gestión ambiental, como la planificación territorial y las licencias ambientales. Todos estos elementos ratifican que el marco regulatorio ambiental en Colombia ha sido insuficiente hasta la fecha para manejar el impacto antropogénico en los ambientes costeros, debido a que no se tiene en cuenta la susceptibilidad natural al efecto de las intervenciones humanas. En este trabajo se define susceptibilidad como la predisposición de una unidad ambiental (sistema socio-natural) para experimentar cambios o afectaciones debido a la introducción de una intervención humana.

Con el fin de proponer mejoras al sistema ambiental colombiano, el **Capítulo V** *plantea un nuevo modelo conceptual y metodológico para guiar la evaluación, el seguimiento y el control de los* *impactos humanos desde una perspectiva geomorfológica*. Este producto novedoso se ha denominado *Susceptibilidad a las Intervenciones Humanas con fines de Licenciamiento Ambiental* (SHIELP en inglés). La arquitectura de este modelo tiene tres componentes, que son particulares para un tipo de entorno, a saber, procesos geomorfológicos, configuraciones geomorfológicas e intervenciones humanas potencialmente impactantes. Cada uno de estos componentes se traduce en una variable por medio de calificaciones de expertos y el cálculo de lógica difusa. Por lo tanto, el sistema experto-difuso SHIELP cuantifica la susceptibilidad de una geoforma distintiva a los efectos de un tipo característico de intervención humana, a través de la perturbación estimada en cada proceso geomorfológico que configura el tipo de ambiente en estudio. Como demostración, este capítulo también documenta el diseño del sistema experto-difuso para ambientes costeros, esbozado en talleres de investigación con miembros del Instituto de Investigaciones Marinas y Costeras "José Benito Vives de Andréis"- INVEMAR. El rol que cumple este instituto como asesor oficial de las autoridades ambientales en cuestiones de evaluación de impacto, demuestran su pertinencia para soportar la base de conocimiento experto del modelo.

Como resultado, el modelo SHIELP se aplicó con los parámetros establecidos para los entornos costeros, derivando en una base de datos de valores de susceptibilidad para 4,524 interacciones (configuración litoral frente a intervención). La aplicabilidad real de este ejercicio corresponde a la traducción de esta base de datos en un criterio técnico para mejorar el marco regulatorio colombiano. Por un lado, cinco rangos de susceptibilidad se vincularon a cinco instrumentos diferenciados, dos de los cuales articulan el licenciamiento ambiental con planes territoriales, mientras que los otros diferencian el tipo licenciamiento pertinente según las propiedades de ubicación de la intervención (screening). Por otro lado, los instrumentos diferenciados también se combinaron con cuatro grados de requisitos de información para la definición del alcance en los estudios ambientales respectivos (scoping). De esta manera, el valor de susceptibilidad de una intervención dada en una configuración determinada (interacción) se ajusta a un rango percentilico que establece la competencia territorial (regional o nacional) para su control ambiental, así como un instrumento de licencia específico con requisitos de información diferenciados para la definición de la línea base ambiental.

Finalmente, la operación del modelo SHIELP se demostró con un estudio de caso: la unidad ambiental costera Rio Magdalena - complejo Canal del Dique - sistema lagunar Ciénaga Grande de Santa Marta. La información geográfica de esta unidad costera regional se interpretó de acuerdo con los parámetros definidos en el modelo SHIELP para ambientes costeros. Se delimitaron 154 polígonos en el área de estudio, de acuerdo con las 40 configuraciones litorales identificadas. Como resultado, 13 mapas cartográficos representan esta área, con los niveles de susceptibilidad atribuidos a cada configuración para las 52 intervenciones potencialmente impactantes. A fin de ilustrar la aplicabilidad del modelo, se presentan cuatro escenarios para discriminar las intervenciones por instrumento de manejo ambiental (screening) y para definir los requerimientos de información sobre procesos geomorfológicos (scoping). De esta manera el modelo SHIELP especifica el instrumento de licenciamiento ambiental para las intervenciones humanas y el alcance correspondiente del estudio técnico requerido, dadas las características de su interacción con la configuración gemorfológica.

Las **Conclusiones Generales** documentan reflexiones y recomendaciones al Sistema Nacional Ambiental colombiano (SINA) para implementar los resultados de esta investigación. Además, este trabajo abre una perspectiva amplia para futuras investigaciones en el enfoque de la susceptibilidad al efecto de las intervenciones humanas. El modelo SHIELP para entornos costeros se puede replicar en diversas geografías para articular progresivamente una base de datos nacional de susceptibilidad costera. Asimismo, el esquema metodológico presentado puede aplicarse en diferentes tipos de entornos, distintos de la zona costera. La ampliación de este enfoque de susceptibilidad geomorfológica sobre la variedad de ecosistemas tropicales, establecería el camino para una transición exitosa desde la actual concepción antropocéntrica y orientada a la fragmentación, hacia una aproximación del manejo basado en los ecosistemas.

GENERAL INTRODUCTION

i. Prologue

This document presents the first doctoral thesis in Earth Sciences of the EAFIT University, focused on the principles of coastal geomorphology and the challenges of the environmental control of human interventions in the Colombian context. These topics reflect the interception between the backgrounds of the doctoral candidate: graduate and professional experience on environmental engineering and postgraduate studies on marine-coastal management.

The doctoral research was developed within the academic program of June 2015 - December 2018, supported by an internal grant of the EAFIT University. This scholarship was raised by the late researcher and academic, Michel Hermelin Arbaux, whose unfortunate sunset (August 2015) coincided with the beginning of this doctoral program. Therefore, the fulfillment of this doctoral thesis celebrates once again the memory and remarkable academic live of this emeritus professor of the EAFIT University.

Complementary, the doctoral research was incubated during the development to the project: *The importance of anthropic interventions on the morphological changes of the Colombian Caribbean coast (18th century to the present),* formulated by Professor Ivan Correa. This project was partially sponsored by the call for projects with internal financing of the EAFIT university during the year 2016, which included enriching interactions with international researchers invited to field trips at the southern Caribbean coast of Colombia (Urabá Golf and Arboletes).

As a result of the collaboration in the former project, an opportunity was opened for the doctoral candidate to perform the mandatory international research stay of the academic program with the Florence University (Italy) during the summer of 2017. Complementary and shorter research stays in Spain and Cuba were completed in the rest of 2017. The direct interaction with several environmental authorities in Italy, Cuba, Spain, and Colombia strengthen the doctoral research arguments about the conventional approach of environmental licensing and its limitations with respect to the particularities of the dynamic coastal environment.

Finally, the call for projects with internal financing of the EAFIT University supported the progress of the doctoral research during the last two years of the doctoral program with the project: *Conceptual model for the evaluation, monitoring, and control of the environmental impact of anthropic interventions on Colombian coastal zones,* formulated by the doctoral candidate. This project has accomplished the following results: a) generation of new knowledge, through the elaboration of three research article manuscripts, one published (Chapter II) and other two already submitted (Chapters III and IV); b) research, development and innovation products, through the 13 cartographic maps detailed in Chapter V; c) social appropriation of knowledge, through the presentation of the research in three international events in Santa Marta (Colombia), Guatemala City (Guatemala) and San Luis (Argentina); d) Inter-institutional cooperation, through the co-authorship of a manuscript from a foreign study area, accepted for publication to Marine Policy on 29-Dec.-2018 (attached in the annexes folder of this thesis); and 5) Training of human resources, through an undergraduate thesis and the semiannual lecture "*Impacts over Nature*", both within the Bachelor in Geology at EAFIT University.

In the main, these experiences contributed to decant the conceptual approach of the doctoral research on the role of geomorphological processes in characterizing the **S**usceptibility to the effect of **H**uman **I**ntervention for **E**nvironmental **L**icensing **P**urposes. This novel conceptual approach has been baptized as the SHIELP model, both for the acronym and for its catching similarity with the science fiction agency S.H.I.E.L.D. (from the popular comic's publisher MARVEL). Taking advantage of this happy typing coincidence, instead of assembling the world's most powerful response team to imminent global threats (superheroes), the SHIELP model assembles the most relevant phenomena whose response to anthropogenic perturbations holds the key to prevent and control imminent damage to geomorphological features. In other words, this first doctoral thesis in Earth Sciences of the EAFIT University is an open invitation to the future vision, instead of just the past, to the new geological epoch: The Anthropocene.

ii. Background and justification

Geomorphology discipline or disciplines?

According to the thorough revision of Lopatin and Zhirov (2017), geomorphology is an autonomous science within the pull of Earth sciences, because it is the only scientific discipline addressing forming attributes. Nevertheless, the review also recognizes that geomorphological knowledge advances along with related Earth sciences, such as physical geography, soil sciences, geo-techniques, geology, and topography. For instance, the same authors stress that while topographic approaches represent the terrain relieve through a system of isohypses, geomorphology discerns the relief's geometry from these inputs for further analysis of its properties. At the same time, Panizza (1996a) differentiate geomorphology from geology through the vertical and historical location of the geological objects of the landscape, because the former considers the objects on the terrestrial surface that are observable at present, while the latter analyses all underlying objects that have experienced historical changes. In the main, the subject matter of geomorphology involves the properties of the topography of land cover, or terrain relief, which includes the form, origin, age and forming processes (Lopatin & Zhirov, 2017).

Consequently, geomorphology can be defined as the study of the landforms characteristics and the forming processes that shape and sculpture the landscape (Scheffers, May, & Kelletat, 2015). This reasoning implies a process-based interaction among several geomorphic elements, which transcend the traditional approaches around sediments, lithology, and morpho-dynamics, to includes a biogenic and human component. For instance, Meitzen et al. (2013) appeal to the terms of biogeomorphology and ecogeomorphology to support the argument about the role of geomorphology in environmental flows. These emerging disciplines stress that biologic and geomorphic processes maintain a bidirectional influence. At the same time, the term 'anthropogenic geomorphology' has gradually evolved from the rising scientific interest on the human influence over the natural topography of the Earth surface, and the creation and environmental impact of man-made landscapes, such as land reclaimed from sea, artificial lakes, and channels, among many examples (J. Li, Yang, Pu, & Liu, 2017). Such interest on the great changes induced by man in natural processes and the related impacts has inspired the definition of 'Anthropocene' as a new geological period (Subcommission on Quaternary Stratigraphy, 2016). Overall, these emerging research lines on geomorphology evidence the need for transdisciplinary studies to address a modern understanding of the environments for its ultimate management.

Following the reasoning of the grosser discipline, coastal geomorphology focusses on the characteristics and the processes originating and shaping the landscape of a distinctive kind of environment: the coast (Kelletat, 1995). Most of the textbooks about coastal geomorphology addresses the littoral classification schemes and their contents are often structured according to distinctive littoral landforms, namely deltas, estuaries, cliffs, tidal features, beaches, dunes, spits, lagoons or corals (Gutierrez, 2008; Masselink, Hughes, & Knight, 2011; Pranzini, 2004). Other references also give additional attention to the morpho-dynamic processes involving marine-driving forces, such as waves, tides, currents or sea level fluctuations (Bird, 2008; R. Davidson-Arnott, 2010; Kelletat, 1995). Further climatic approaches are also introduced in general geomorphological classification of coastal features (Kelletat, 1995; Pranzini, 2004). Aside from the terminology and the conceptual framework, there is an increasing rate of geomorphological studies with a management approach due to the anthropogenic view of coastal erosion as a hazard (Bush, Pilkey, & Neal, 2001; Cooper & Pilkey, 2012; AT Williams, Rangel-Buitrago, Pranzini, & Anfuso, 2018). In reality, the erosional trend of the shorelines is only a problem when faced with mankind´s inability to prevent vulnerable locations during the advance of civilizations. In the main, the anthropogenic effects on coastal environments have distinctive geomorphological manifestations, which must be qualified within the subjects of environmental impact assessments.

Environmental impact

As previously stated, the human role on the changes and evolution of natural settings is an increasing concern because the mankind perpetuation is threatened by the feedbacks of the human-landscape system (Chin, Florsheim, Wohl, & Collins, 2014). The pressing signs of environmental deterioration in populated locations anticipate obscure scenarios for sustainable development in the face of increasing rates of population growth (Barragán & de Andrés, 2015). This situation has risen the need for robust environmental management instruments to control the effects of aggressive industries, infrastructure developments and exploitation of natural resources (Joseph, Gunton, & Rutherford, 2015).

In this context, the Environmental Impact Assessment (EIA) figures as such instrument in which the effects of a proposed human intervention on a socio-natural system are identified, quantified and further evaluated for the design of management measures, such as prevention, mitigation and otherwise remediation and compensation (IAIA & IEA, 1999). When the human intervention transcends the local scale of a project, built structure or activity, to comprehend groups of them in a plan, policy or program, the impact evaluation turns into a Strategic Environmental Assessment (SEA). In the main, the outcome of such environmental assessments supports the decision making for an administrative entity to allow or deny the permit for executing the proposed human interventions. Therefore, this assessment contributes to the environmental evaluation, monitoring, and control of the impacts triggered by human interventions on natural settings.

Three technical elements are important in these impact assessments: baseline definition, evaluation methods, and management plans. The baseline comprehends the characterization of the area that would be subject to the changes induced by the proposed human intervention. Such description of the current state of a socio-natural system derives from the revision of existing data, gathering of new data and the processing and interpretation of both sorts of data sources (Durden et al., 2018). On the other hand, the methodologies for the identification and evaluation of impacts is one of the weak points in environmental assessments. The methods often accepted by users and stakeholders are the ones lacking scientific robustness, highly reliant on subjective inputs and incapable of producing useful outputs given the technical content and volume of the baseline information (Joseph et al., 2015).

For the identification of impacts and influence area, common methods comprise pre-established checklist, cause-effect matrices, web diagrams, expert panels or superposition of thematic maps; but the common element in those activities is the integration of a multi-disciplinary team for discussions on the assessment case. Furthermore, the evaluation of impacts is conducted through qualitative or quantitative methodologies. The former often involve matrices for defining impact importance though several attributes, such as magnitude, intensity, nature, effect manifestation or recoverability, among many (Conesa, 2006; Leopold, Clarke, Hanshaw, & Balsley, 1971; Toro, Requena, Duarte, &

Zamorano, 2013). The latter ones involve the comparison of environmental factors measured in present conditions, without intervention, and the simulation of their variation in the scenario with intervention, However, this factor's indicators are most likely physical, chemical, microbiological an ecological parameters translated into environmental quality units through transformation functions. In order to overcome the imprecisions implicit in the prediction of impacts, emerging methods are combining traditional approaches with fuzzy logic computation, which take advantage of linguistic variables for concepts without exact frontiers (Liu & Lai, 2009; Peche & Rodríguez, 2011).

Overall, the workflow of an impact assessment comprises the identification of environmental factors and elements, normally segmented into biotic, abiotic and social components, the identification of interventions' activities with potential effect and the identification of environmental impacts. Next, the impacts must be evaluated through either of the methodological approach aforementioned with the purpose of prioritizing the impacts according to their significance in the overall assessment. Those significant impacts must be finally managed through the design of an environmental management plan for the lifetime of the intervention, which includes the installation, operation and decommissioning (Durden et al., 2018). This plan includes the measures of prevention, reduction, restoration and compensation of impacts, along with the appropriate program of monitoring to follow up the accomplishment of the environmental management compromises. Lastly, the universe of environmental assessments comprehends several actions complementary to the impact assessment, such as the analysis of intervention's alternatives and risk assessment. Emerging methods in this regard are also evolving, such as economic assessments through cost-benefit analysis or multi-criteria assessment through analytical hierarchical processes (Joseph et al., 2015; Robles, Polo, & Ospino, 2017).

Coastal environmental zoning

Coastal zone may be considered as a term defining the limits of a geographical area involving the land-sea interface, but with an underlying management purpose. For instance, Barragan (2003) uses the term littoral area when referring to a geographical scope and coastal zone when the boundaries of such area decant from the purposes of planning and management. In this sense, several technical and legal-administrative criteria may be taking place in the different approaches conceived for the sustainable development of the coastal environment, a practice that has been labeled as ICZM: integrated coastal zone management (Milanes, Suarez, & Botero, 2017; Vallega, 1999). This is how the Encyclopedia of Coastal Sciences has consolidated nine criteria for establishing coastal boundaries, including biological and physical-natural features, political-administrative issues, fixed distances (e.g. the nautical miles of the territorial sea), particular management issues (e.g. territorial development or environmental conservation goals) and historical memory (Milanes, 2018). Figure i provides a simplified representation of the interaction of some of these criteria within the establishment of limits for the planning and management of the coastal zone.

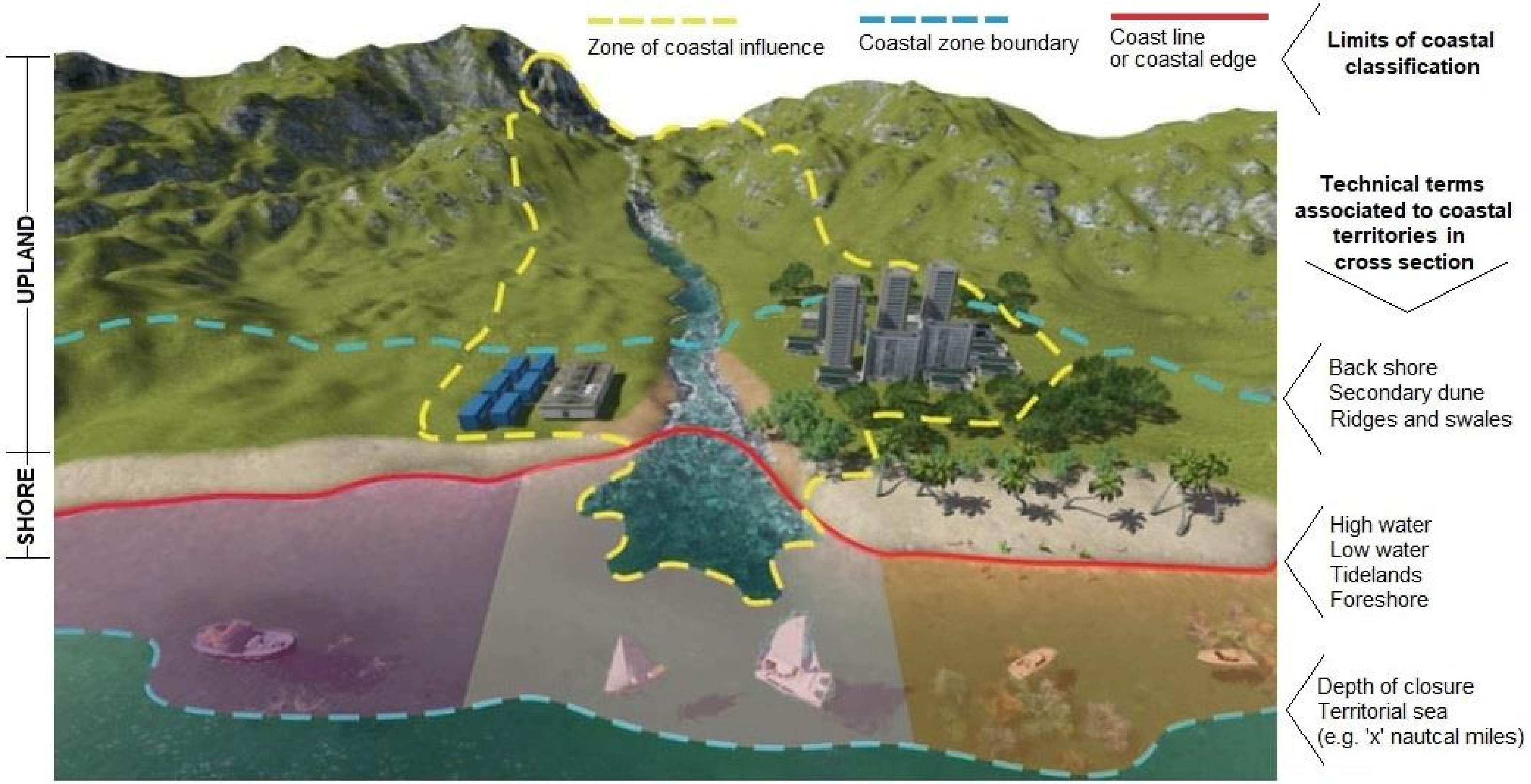

Figure i. Aerial view of coastal limits used for land-sea planning and integrated coastal zone management. Modified from Milanes (2018)

One of the main objectives in coastal delimitations has focused on the management of risk due to environmental hazards. Isolated studies all over the worlds addresses the natural conditions, evolution, and vulnerability of coastal zones to specific hazards, such as shore erosion, sea level rise, storm surge or pollution (Anfuso & Martínez-del-Pozo, 2009; Epifânio, Zêzere, & Neves, 2014; Fitton, Hansom, & Rennie, 2016; Gómez, Ondiviela, Fernández, & Juanes, 2017; Goodhue et al., 2012; Mahapatra, Ratheesh, & Rajawat, 2013; Mcfadden, 2010; Newton & Weichselgartner, 2014; Rangel-Buitrago & Anfuso, 2015; Satta, Snoussi, Puddu, Flayou, & Hout, 2016; Torresan, Critto, Rizzi, & Marcomini, 2012). However, these studies do not address the void of practical knowledge for supporting the environmental assessment of projects and leave aside the adverse effect generated by human interventions. Therefore, the environmental zoning of the coastal zone is a pertinent approach for addressing impact management issues. And this approach should recognize the particularities of the coastal landforms, which is given by the configuration of both emerged and submerged features.

In Colombia, the coastal environmental zoning was first introduced by the environmental national policy for the sustainable development of oceanic areas and coastal and insular zones of Colombia (MMA, 2000). This policy establishes three regions subdivided into 12 environmental units, ten coastal and other two oceanic, regarding the jurisdictional waters beyond the isobaths of 200 meters (see Figures ii and iii). Thus, the Caribbean insular region comprehends one coastal unit, the Caribbean continental region comprises five coastal and one oceanic, and the Pacific region contains four coastal units and one oceanic.

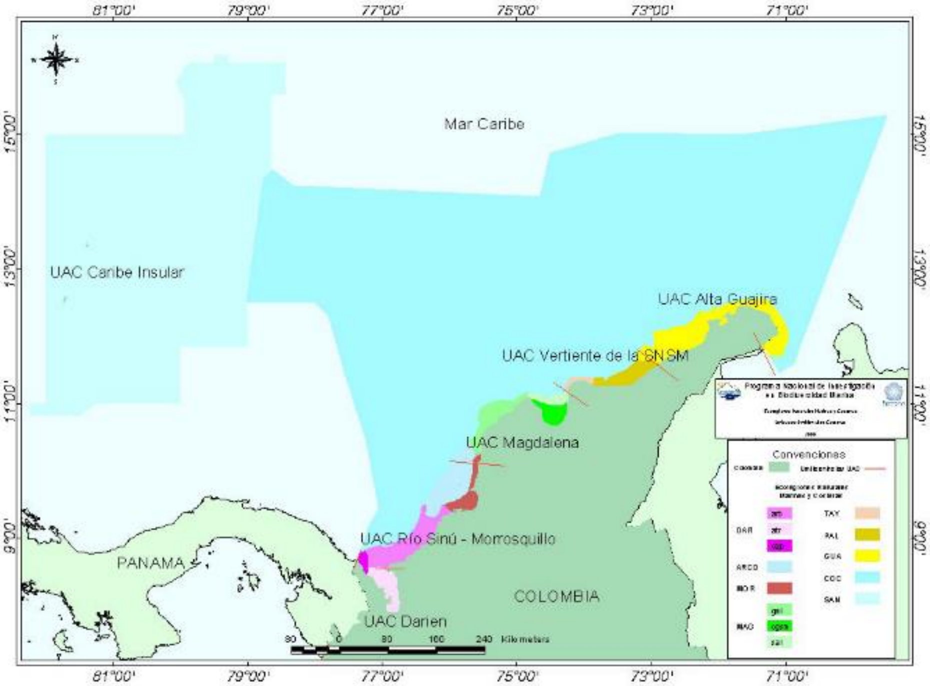

Figure ii. Environmental units of the Colombian Caribbean regions. Taken from MMA (2000)

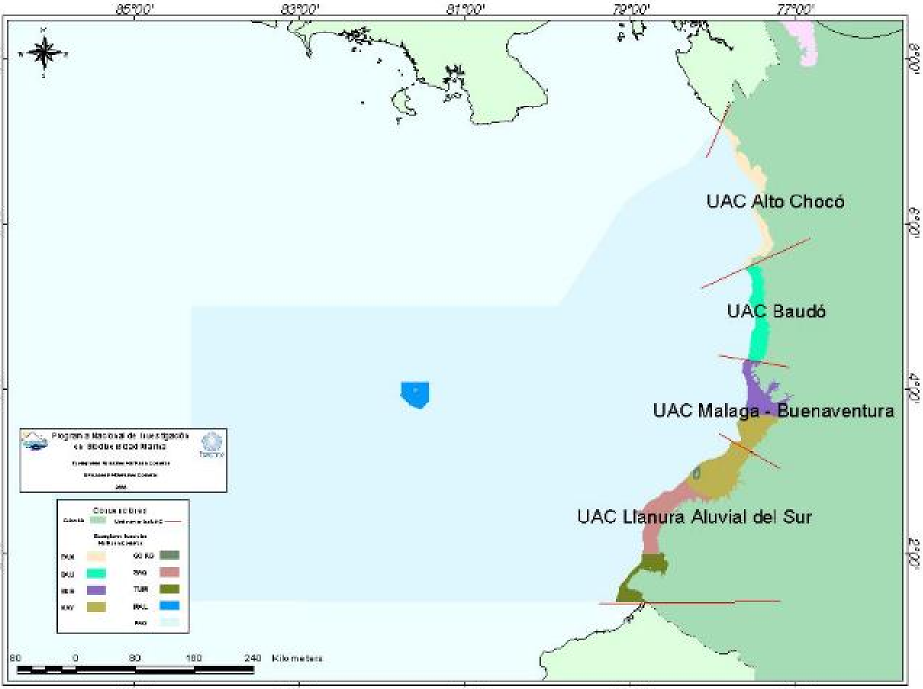

Figure iii. Environmental units of the Colombian Pacific region. Taken from MMA (2000)

Based in this policy, the Decree 1120 of 2013 made official the environmental zoning of the ten coastal units to make progress toward their integrated management throughout structured plans, called POMIUAC by the Spanish acronym (integrated management and order plan of coastal environmental units). The delimitation is declared to be based on distinctive ecosystems with similar structural connectivity and functionality. In this regulation, the coastal zone boundaries are set at two kilometers inland from the shoreline, transition vegetation or lagoon flooding mark, and until the 200 meters isobaths in the sea. The boundaries along the shore are normally set by a physical pattern, such as rivers.

Justification

Increased productive, industrial and commercial activities associated with the phenomenon of demographic densification in the coastal zones has triggered an unplanned territorial development in the Colombian Caribbean coast (Barragán & de Andrés, 2015; Cochero & Manjarrez, 2014; Rangel-Buitrago, Anfuso, & Correa, 2012). Infrastructure works linked to these developments, such as the jetties at Bocas de Ceniza in the Magdalena river mouth or the diversion of natural currents of lower order, have been responsible for the instability of coastal areas and the consequent modification of environmental conditions (Correa, Alcántara-Carrió, & González, 2005; Rangel-Buitrago, Anfuso, & Williams, 2015). The pressure imposed by uncontrolled human uses and activities causes coastal ecosystems to exceed their capacity for self-regulation, thereby increasing the vulnerability of coastal areas to natural threats of marine or terrestrial origin (Botero, Anfuso, Rangel-Buitrago, & Correa, 2013; Stancheva et al., 2011). Thus, unplanned territorial development represents a challenge for risk management and entails high costs of social and environmental protection for coastal populations and settlements (Cooper, Anfuso, & Rio, 2009; INVEMAR, 2003).

There are several studies at local and regional scales about the natural conditions of the Colombian Caribbean coast, its evolution and its vulnerability to specific hazards, such as sea level rise (DIMAR-CIOH, 2009a, 2009b, 2013; IDEAM, 2001; INVEMAR, 2003). These studies have focused mainly on natural hazards, leaving aside the adverse effect generated by human interventions, or considering it only as one more element in the general vulnerability assessment. However, the holistic perspective of the XXI century imposes the need to study beyond merely one-way of the effects, which includes the interactions nature-mankind addressed by the Anthropocene epoch.

In terms of environmental impact, the concept of vulnerability has been used to describe the physical, biotic and social susceptibility of natural systems to damages or threats by the construction, operation or decommissioning of projects, built structures or activities (Toro, Duarte, Requena, & Zamorano, 2012). Therefore, it is pertinent to focus the analysis of physical-biotic susceptibility of littoral areas against the effects of coastal interventions, so that environmental licensing processes have a conceptual and methodological reference to reduce subjectivity in the environmental assessment regulated in Colombia. Thus, this research focuses on the approach of physical-biotic susceptibility, not on coastal vulnerability, because the socio-economic dimension is beyond the direct reach of Earth Sciences.

iii. Study area, hypothesis, and objectives

This research analyses the environmental regulatory framework to manage human intervention in the Colombian coastal zones throughout two geographical levels. On the one hand, the characterization and analysis of human interventions were set at the gross scale of the Caribbean continental region. This can be considered a significant sample of the Colombian context because this region endures higher levels of human occupation and therefore presumed anthropogenically-induced perturbations. On the other hand, the detailed scale of an environmental coastal unit (ECU) was defined to test the conceptual and methodological approach derived from this research. The selected unit was the “Magdalena River - Canal del Dique complex - Ciénaga Grande de Santa Marta lagoon system” (ECU Mag-Dique), because it reports the higher availability of geomorphological information from official sources.

The thesis is motivated by the situation in the Colombian Caribbean, where different types of coastal projects and activities have derived in negative effects, associated with littoral instability and generalized degradation of physical-biotic conditions. The major geomorphological changes aforementioned suggest an inadequate environmental evaluation, monitoring, and control of human interventions. These functions are sorted through the environmental licensing procedure (ELP), which in Colombia is implemented by national and regional environmental authorities (Law 99 from 1993). Therefore, the following **hypothesis** arises: *Colombian environmental regulatory framework is insufficient for managing the effect of human interventions in coastal environments from a geomorphological perspective*.

This statement suggests the following **research questions**: *What elements of environmental licensing in coastal environments can be improved from a geomorphological perspective? How the environmental regulatory system in Colombia has evolved regarding the human interventions influencing the coastal environment? What technical improvements can be made in the Colombian regulatory framework to guide the impact assessment, monitoring, and control of human interventions from a geomorphological susceptibility approach?*

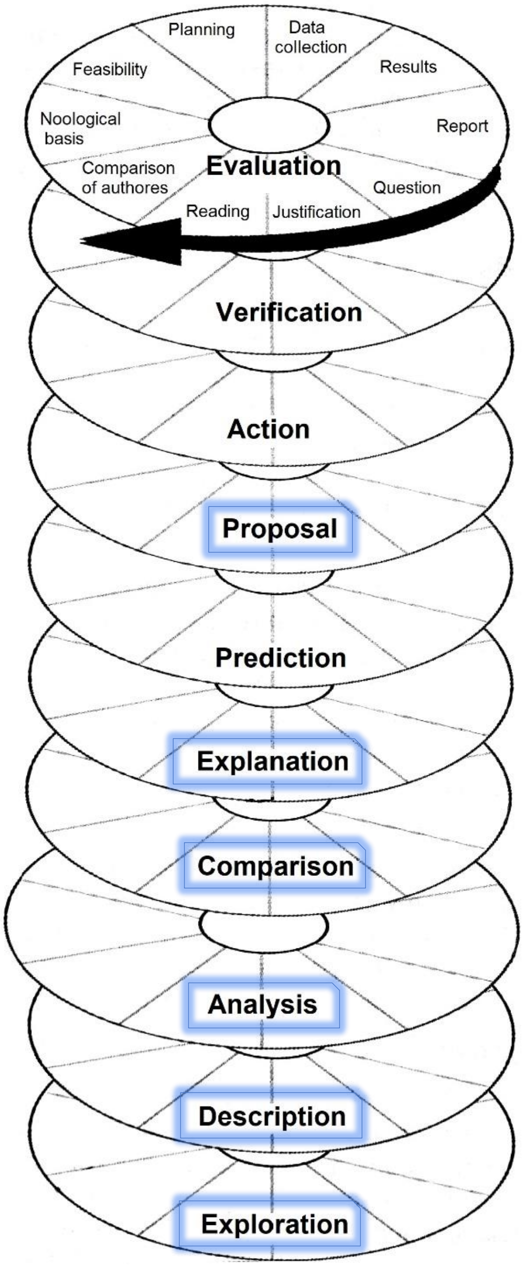

Figure iv. Holistic cycle of the scientific research. Adapted from Hurtado (2010)

The **general objective** of this thesis is to *propose adjustments to the Colombian environmental licensing procedure to guide the evaluation, monitoring, and control of human impacts from a coastal geomorphological approach of susceptibility*. To reach this goal, the general methodology of the thesis relies on the holistic cycle of scientific research with a quantic process, according to Hurtado

(2010). Therefore, each chapter of the thesis contributes to the main goal through the exploratory, descriptive, analytical, comparative, explicative and proactive research stages (see Figure iv).

The **specific objective** achieved by chapters I and III is to *characterize the geomorphological settings and human interventions in the continental Caribbean coast of Colombia*. The first chapter registers the results of exploratory and descriptive research stages, in which the historical-geomorphological changes of the Colombian coasts are analyzed. Similarly, the third chapter consolidates a baseline of the environmental impact of the continental Caribbean coast of Colombia through an inventory of human interventions, which correspond to a descriptive stage of the holistic research cycle.

The **specific objective** achieved by chapter II is to *identify the geomorphological perspective in the Colombian ELP through the comparison with foreign environmental regulatory frameworks*. This chapter represents the comparative research stage to assess the environmental regulatory framework of three countries (Italy, Spain, and Cuba) as opposed to the Colombian one.

The **specific objective** achieved by chapter IV is to *assess the scope of the Colombian regulatory framework according to the environmental licensing of interventions affecting the coastal zone*. As an analytical research stage, this chapter correlates the coastal policies and EIA regulations with the inventory of human interventions, to ascertain the limitations and weaknesses of the Colombian ELP.

Finally, the **specific objective** achieved by chapter V is to *establish a conceptual and methodological approach to guide the Colombian environmental licensing procedure in coastal environments from a geomorphological perspective*. This chapter relies on two stages of the holistic research cycle. On the one hand, the conceptual approach of susceptibility to the effect of human interventions for environmental licensing purposes results from an explanatory stage. On the other hand, the methodological approach of this conceptual model and its application to the ECU Mag-Dique represents the proactive research stage.

iv. Critical analysis of the background

Geomorphology and environmental management

Downs and Booth (2011) have distinguished three main roles of geomorphology in environmental management issues, namely natural hazard definition, conservation of natural settings and the sustainable exploitation of natural resources. Within their literature review about applied geomorphology, these authors conclude that most publications correspond mainly case studies rather than the reference of actual application of geomorphological techniques and approaches to support an environmental management situation. As an instrument for environmental management, such as territorial planning or resource conservation policies, the environmental impact assessment (EIA) demand on geomorphological services in terms of tools for evaluating the effects of human activities on geomorphological features (Panizza, 1996b). Therefore, there is a close relationship between geomorphology and EIA despite the superficial interest that the Earth Sciences community has traditionally put on the general environment (Cendrero, Marchetti, Panizza, & Rivas, 2001).

In a quick revision, the literature addressing the role of geomorphology in the EIA seems rather limited (Downs & Booth, 2011). A relevant conceptual referent in these regards dates back nearly two decades when Cendrero et al. (2001) differentiate landforms from processes among the geomorphological components that need to be identified in an EIA. According to this argument, the characterization of landforms leads to defining the direct impact of one human intervention in terms of environmental damage or economic loss of natural assets; meanwhile, the processes characterize the damage to a human development due to geological hazards. In other words, landforms play a passive role because they are being threatened by human activity, but the processes play an active role because they set risks to projects or activities. However, this traditional approach also states that processes produce landforms (Panizza, 1996b), which implies that processes play both passive and active roles regardless of the relationship direction between human activity and geomorphological features. Therefore, the natural processes are the backbone of the role geomorphology plays on environmental management issues.

In the main, the geomorphology discipline has played an important role in the general evolution of the EIA. For instance, one of the first process-based studies on the human role on land transformation is with Leopold (1956), which turned out to be one of the seminal referents about the management application of geomorphology in the 20th century (Downs & Booth, 2011). What is more interesting is how the same author led a proposal from the U.S. Geological Service to homogenize the preparation of environmental impact statements (EIS) or reports required from the authority about the effects of a project (Leopold et al., 1971). This procedure was conceived to improve uniformity in the impact's analysis between report generators and evaluators through a system of matrixes crossing natural factors and project's activities. Even though this method is still being thought as a multidisciplinary approach in EIA guidelines, it is basically a contribution from the geomorphology discipline, born and raised in the core of a geological service.

Coastal Geomorphology and the natural processes

Most textbooks of coastal geomorphology are not specifically structured by the natural processes shaping this landscape, but several chapters often refer to coastal processes. For instance, Kelletat (1995) differentiate constructive, protective and destructive coastal processes in a chapter section about littoral processes, together with separate chapters of particular landforms driven by exogenic and endogenic processes. Masselink et al. (2011) include separate chapters about sea level, tides, waves and littoral features dominated by some of these forces as well as fluvial and geological controls. Davidson-Arnott (2010) comprises a section about coastal processes, describing sea level fluctuation, waves, wind-generated waves, surf zone circulation, and sediment transport. Similarly, Bird (2008) articulate wave, tides, storm surges, tsunamis, currents, nearshore water circulation, wind action and complementary processes in a single chapter about coastal processes.

In sum, coastal processes are only referred as those influencing the littoral boundaries, represented by the offshore point where the wave starts moving sediment within the marine floor and the inland limit under the marine influence or back beach (Bird, 2008; Milanes, 2018; Sorensen, 2006). However, Figure i indicates how the coastal zone is more comprehensive and thus, the processes influencing the coastal morphology cannot be excluded to those of marine origin (Pranzini, 2004). Instead, a geomorphological approach should consider a wider range of contributions that comprehend the gross shore and upland segments encompassing the coast. In this sense, the ***definition of geomorphological processes*** upon which this research is supported ***refers to a set of complex phenomenon describing the mechanism through which matter and energy flow along a type of environment and contributes to reach and maintain a morphological configuration***. Therefore, instead of misleading the audience with the traditional understanding of coastal processes as the marine-driving forces, this research refers to the natural processes influencing the coastal morphology.

In an attempt to distinguish these natural processes, six categories can be extracted from the relevant literature. Firstly, the processes under the geological category refer to those originating the Earth crust, within which endogenic and exogenic processes are combined and mixed up (Kelletat, 1995). These processes are also strongly related to the morphological characteristics and lithological nature of coastal environments (Brito, 2012; Masselink et al., 2011). Secondly, the processes on the geochemical category refer to the transformation and modeling of the Earth Crust, while the ones on the climatic category also adds up to the modeling of the Earth Crust, but may also share the character of exogenic processes when referred to extreme short-term events (Bird, 2008; Kelletat, 1995; Morton & Pieper, 1977). Finally, the processes under the hydrodynamic, eolic and biogenic categories share all the characteristic of being driven by or related with, littoral agents that shape the land/sea interface in coastal environments (Pranzini, 2004; Prothero & Schwab, 2013).

Environmental licensing procedure (ELP)

When dealing with topics of EIA, scientific literature often refers indistinctively to the technical exercise of impact assessment and to the set of regulatory procedures required for approving or denying the implementation of a project, built structure or activity (Chanchitpricha & Bond, 2013; Del Furia & Wallace-Jones, 2000; Enríquez-de-Salamanca, Martín-Aranda, & Díaz-Sierra, 2016). For instance, there is a separated section titled 'EIA' when Durden et al. (2018) analyzes the practice of EIA on the activity of deep-sea mining, which implies that the EIA term is playing both roles as a procedure and as one of the activities within. In view of this bivalence, several authors have opted to use the term of environmental licensing for addressing to what other authors refer as the EIA system or EIA process (Bragagnolo, Carvalho Lemos, Ladle, & Pellin, 2017; Burgel, da Silva, de Souza, & da Rocha, 2017; Jaskoski, 2014; Lima & Magrini, 2010; Monteiro & da Silva, 2018; Villarroya, Barros, & Kiesecker, 2014). Therefore, it is pertinent to establish the difference between the EIA, as a technical exercise, and the environmental licensing procedure (ELP), as the administrative protocol enacting the impact management through a license or permit.

As a procedure, environmental licensing must be structured by phases, which can be interpreted from the operating principles of best practice in EIA systems. The International Association of Impact Assessment (IAIA) have conceptualized ten different operating principles, and at least six of them can be recognized as phases for issuing an environmental license. At first, the screening phase represents the procedure or normalized criteria that define whether a human intervention requires to undergo a full licensing and to what degree. Then, petitioners and/or authorities identify the issues and impacts that must be addressed in the impact assessment during the scoping phase, which included details on the baseline definition. The third phase would be the preparation of the environmental impact statement (EIS) or report by the license's petitioner, which documents the examination of alternative, the impact analysis, the evaluation of impact's significance and the management measures. The following phase would be the revision of the EIS by the environmental authorities in charge of assessing the sufficiency of the report. Next, the phase of decision making corresponds to the denial or approval of the license with the necessary conditions for its implementation. And finally, the follow-up phase extends during the operation and decommissioning of the intervention, when the environmental compliance of the approved licenses is monitored through periodic reports and/or audits. In the main, each territorial administration implements these phases in diverse manners according to the regulatory context of the country.

In this sense, the ELP becomes the regulatory facet of the EIA, as an environmental management strategy for human interventions. And it is the weakest facet because it has a more administrative than technical component (Bragagnolo et al., 2017; Castley, Bezuidenhout, & Knight, 2003; Enríquez-de-Salamanca, 2018; Aled Williams & Dupuy, 2017). Therefore, it is pertinent to analyze the technical guidelines ruling the ELP in a given territory for contributing to their improvement through scientific advances. In this way, the technical milestones of ELP can evolve towards better robustness and effectiveness for their ultimate purpose as a management instrument to reduce the human impact.

Finally, the current institutional framework of the ELP in Colombia was set from the Law 99 of 1993, which created the Ministry of Environment and structured the national environmental system SINA (in Spanish, Sistema Nacional Ambiental) with the ministry, research institutes and regional environmental authorities. This regulation defines the national responsibility of environmental licensing over the Ministry of Environment and over autonomous corporations at the regional level. During the year 1994, three different decrees created five research institutes as part of the SINA, which was conceived to support the national and regional authorities in the generation of knowledge for the environmental management of the national territory. The next institutional milestone was the creation of the national authority of environmental licensing ANLA (in Spanish, Autoridad Nacional de Licencias Ambientales), with the Decree 7576 of 2011, which rules as an annex of the Ministry of Environment that takes over its ELP responsibilities. In parallel, the institutional competences and further dispositions of the ELP have evolved through six different decrees between the years 1994 and 2014 (Decree 1753 of 1994, Decree1728 of 2002, Decree 1180 of 2003, Decree1220 of 2005, Decree2820 of 2010 and Decree 2041 of 2014). The last of this is compiled in the current Unique Environmental Decree 1076 of 2015.

Environmental information status of the Colombian coastal zones

Despite the national efforts to make amends for the delay on ICZM, the state of knowledge about Colombian marine and coastal territories is still limited. In fact, the official technical guideline for the elaboration of the POMIUACs has been adopted by the Ministry of Environment up until just recently, with the Resolution 768 of 2017. Therefore, the effectiveness of these management plans is rather poor in the country because the majority of the POMIUACs remain in their formulations stage. This situation poses an additional setback for the effective control of the anthropic impact of coastal interventions due to the inability of coupling environmental management instruments with land and marine planning instruments.

One element aiding to the disarticulation of territorial planning and environmental licensing in coastal zones involve unavailable official data to inspire pertinent technical criteria for characterizing the environment at regional or local levels. The environmental information system for Colombia SIAC (in Spanish Sistema de Información Ambiental Colombiano) is driven by the Ministry of Environment in cooperation with official research institutes to facilitate knowledge generation of the national territory and decision making, among other functions (SIAC, 2018). There is a parallel system attached to the SIAC gathering the marine and coastal information, called SIAM (in Spanish Sistema de Información Ambiental Marino). This specialized information system articulates the environmental information generated, administrated and requested at a national, regional and local level, which feeds from eventual and periodic information mainly produced by the national marine and coastal research institute through automatic monitoring systems (INVEMAR, 2018). The conceptual and technological support of this system is rather powerful, however, the high volume of information does not equal its diversity to represent all natural flows of materials and energies comprised by the process configuring the coastal environment.

On the whole, the general figures reported on the website of SIAM about biodiversity, ecological systems of marine protected areas and species distribution suggest a strong bias over geological variables (INVEMAR, 2018). Periodic information in this system derives from the monitoring programs of water quality for the preservation of fauna and flora and the program of marine ecosystems and biodiversity. More occasional data may derive from the programs of marine geosciences, marine-coastal research for management and marine resources valuation and use. Nevertheless, the scope for the bulk of this data generated is for scientific advances rather than management purposes. An improvement to this system may rely on articulating their inputs with the environmental monitoring of regional authorities with coastal jurisdictions and to homogenize the variables to be monitored by the research institutes and authorities around the natural processes influencing the coastal morphology, besides the ecosystem functioning.

v. Thesis structure

The format of this thesis is manuscript-based, in which four of the following chapters correspond to a different manuscript submitted for publication. Although some of these studies are closely related and share some of the data used, the topics of each chapter are sufficiently different to structure individual manuscripts. The manuscripts are presented identically to the publications with slight changes in formatting. Each chapter's full citation is listed below. In addition, there is a fifth chapter, which is slightly different because two projected manuscripts are merged to ease the argument continuity of the resultant conceptual and methodological proposal of the research. All bibliographic references made throughout the thesis are summarized into a single bibliography section at the end.

The seven chapters structuring this thesis are broken down as follows:

Chapter I – 1st manuscript. It presents an overview of the morphological evolution of both Colombian continental coastal regions, giving particular attention to the Caribbean. This document analyses the historical geomorphological changes from the review of the literature and photographic archives. It comprises descriptions of a general context at each region, including the physical setting and particular phenomena, such as mud diapirism. In consonance with the factors defining the human footprint on the geological registry, as defined by the Anthropocene stratigraphic unit, the final remarks of this manuscript highlight the human role on the biggest historical geomorphological changes of the study area, associated with land use practices, river diversion or infrastructure. In sum, this chapter set the geomorphological characterization of the gross study area of the research and the preliminary analysis of the natural and human elements of the landscape evolution at coastal environments. The full citation of the manuscript is:

> Correa, I.D., Pereira, C.I., 2019. The Historical, Geomorphological Evolution of the Colombian Littoral Zones (Eighteenth Century to Present), in: Cediel, F., Shaw, R. (Eds.), Geology and Tectonics of Northwestern South America. Frontiers in Earth Sciences. Springer, Cham, pp. 957–981. Corrected proofs on 23 Mar. 2018. https://doi.org/https://doi.org/10.1007/978-3-319-76132-9_16

Chapter II – 2nd manuscript. It presents an international analysis of the environmental management of the human impact on coastal environments through the comparison of the ELP in four countries. The geomorphological perspective on this document focuses on the natural processes influencing the coastal environment, which were used as a referent for some comparisons. These processes were identified and cataloged from the official EIA guidelines at each country or territory, in which the technical requirements for baseline definitions are established. In addition, geomorphological variables to delimit the influence area in the impact assessment were also extracted and compared from this EIA guidelines. As a result, the manuscript identifies, compares and synthesize good practices for the ELP in coastal environments from the environmental regulatory framework of four countries.

The full citation of the manuscript is:

> Pereira, C.I., Botero, C.M., Correa, I.D., Pranzini, E., 2018. Seven good practices for the environmental licensing of coastal interventions: Lessons from the Italian, Cuban, Spanish and Colombian regulatory frameworks and insights on coastal processes. Environ. Impact Assess. Rev. 73, 20–30. Accepted 15 Jun. 2018. https://doi.org/10.1016/J.EIAR.2018.06.002

Chapter III – 3rd manuscript. It presents a diagnostic analysis of the human interventions in the Continental Caribbean Coast of Colombia (CCCC) through an inventory pulled from open access satellite imagery. By means of a qualitative approach of impact assessment, this regional study addresses the intrinsic characteristics of the human interventions as the triggering event in the geomorphological changes induced on the coastal environment. Therefore, this manuscript consolidates a baseline of the environmental impact currently affecting the gross scale study area of the research: The Colombian Caribbean coast.

The full citation of the manuscript is:

Pereira, C.I., Madrid, D.A., Correa, I.D., Pranzini, E., Botero, C.M., 2018. Anthropogenically impacted coast: An evaluation of human interventions in the Caribbean Coast of Colombia. Manuscript submitted for publication to Anthropocene, 04-Sept.-2018.

Chapter IV – 4th manuscript. It presents the analysis of the environmental licensing regulatory framework in Colombia against the environmental impact estimated for the types of interventions inventoried in the gross study area of the CCCC. This analysis includes coastal policies and EIA regulations to ascertain the limitations and weaknesses of the Colombian ELP in coastal environments. Therefore, the manuscript stresses the need for articulating licensing instruments with territorial planning instruments through an underlying element: the landforms' susceptibility to the effect of human interventions for environmental management purposes.

The full citation of the manuscript is:

Pereira, C.I., Carvajal, A.F., Milanes, C., Botero, C.M., 2018. Regulating human interventions in coastal areas: policy implications of the environmental licensing procedure. Manuscript submitted for publication to Environ. Impact Assess. Rev., 29-Oct.-2018.

Chapter V – The SHIELP model. This chapter weaves the concept of susceptibility from the role played by geomorphology in the EIA context, where distinctive landforms emulate the environment's resilience to changes triggered by human interventions. In this sense, the geomorphological processes are set as the integrating element of this susceptibility approach, through expert's qualifications of the perturbation of such processes in a given interaction (morphological configuration *vs* human intervention). Naturally, this is the proactive chapter of the thesis that consolidates a conceptual and methodological approach of SHIELP, defines the parameters of the model for coastal environments and demonstrate its operation with the application on the ECU Mag-Dique. It is worth noticing that the work documented in this chapter was supported by the geosciences program of the marine and coastal research institute (INVEMAR, by its Spanish acronym), which opened their information resources and access to experts in coastal processes.

As previously stated this chapter would split into two separate manuscripts, with the following preliminary citations:

Pereira, C.I., Taborda, J., Pranzini, E., Correa, I.D., Botero, C.M., 2019. Susceptibility to the effect of human interventions: design of an expert-diffuse system to improve the environmental licensing of coastal interventions. To be submitted for publication to Environ. Impact Assess. Rev.

Pereira, C.I., Ricaurte, C., Coca, O., Morales, D., Correa, I.D., Pranzini, E., 2019. A geomorphological approach of susceptibility for environmental licensing and application to a Colombian coastal unit. To be submitted for publication to Geomorphology.

vi. Research contributions

New knowledge generation in this thesis mainly relates to the theoretical consolidation of the susceptibility concept in the EIA context through a geomorphological perspective. Since the practical application of the research results lies with the environmental licensing procedure, the Colombian regulatory framework may have a robust conceptual and methodological approach to guide the impact assessment of coastal interventions. In addition, the process-oriented approach that structures the susceptibility concept opens the gate towards a new philosophy to address impact assessment, in which the environmental licensing procedures get discriminated by types of environments to achieve management targets, instead of economic activities.

On the other hand, the inventory of human intervention in the regional scale of the Colombian continental Caribbean represents both practical and methodological contributions. The results of this exercise supply the first diagnosis of the extent of the human perturbation in a coastal zone, as well as a replicable method to perform a similar diagnosis in other regions or environmental units.

Finally, the study case of the susceptibility in an ECU represents the application of the proposed susceptibility approach, which in future researches can be replicated in other ECUs and types of environments other than the coastal zone. Therefore, if implemented, the conceptual and methodological approach of susceptibility to the effect of human interventions would contribute to overcoming the weakness of the environmental regulatory framework identified in Colombia.

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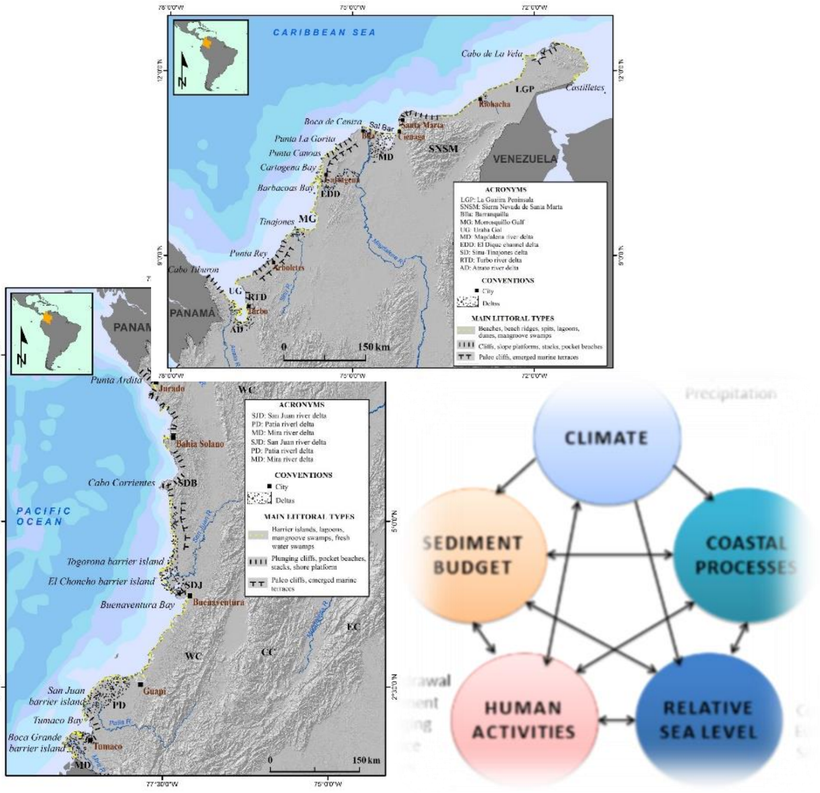
CHAPTER I

The historical, geomorphological evolution of the Colombian littoral zones (XVIII century to present)



1.1. Abstract

The complex geological framework of Colombia is reflected on its Caribbean and Pacific coasts by the highly contrasting nature of their littoral types, ranging from low-relief deltaic barrier islands and mangrove swamps to steep-rocky reliefs cut by plunging cliffs and wide erosional shore platforms. Relative sea-level changes during the Quaternary and the Holocene are evidenced by morphological features of ancient coastline positions, including emerged marine terraces with coral reefs, cliffs, stacks and raised beach ridges deposits.

An overview of the historical evolution of the Colombian littorals since the end of the XVIII century evidences a high morphological instability indicated by coastline changes of hundreds of meters and corresponding land losses or gains of tens of km². These evolutions reflect noticeable variations in the littoral´s sediment budgets, much of them triggered or greatly influenced by human actions. Along the 1,700 km-length, micro tidal Caribbean shores, critical areas are found between the Magdalena delta and the Urabá Gulf, a developed, highly tectonic coastal fringe influenced by mud diapirism and by man induced changes on its hydrological and sedimentological regimes. Along the meso-macro tidal, 1,300 km-length, less populated and engineered Pacific coast (but highly intervened by deforestation and mining), most critical cases are shown by the breaching of its major barrier islands, due only to natural factors including coseismic subsidence, tsunamis and positive sea-level anomalies during El Niño events.

1.2. Introduction

It has long been recognized that human occupation of coastal areas during the last centuries has had profound, cumulative effects on the geomorphology and the environmental quality of populated littoral zones around the world (Eurosion, 2004; Morton, 2002; Pranzini & Williams, 2013). In fact, all the factors considered by the International Geological Program (IGP) to formally define the Anthropocene as a new stratigraphic unit - land use practices, river diversions, sand and fluid extraction, infrastructure building- had greatly modified the natural processes and caused major impacts in many places on the original, pristine nature of the littoral ecosystems (Subcommission on Quaternary Stratigraphy, 2016). Thus, human activities are now considered as one of the main factors in all conceptual frame-works dealing with the evolution of coastal environments (Figure 1.1).

Sedimentary balances result from multiple feedbacks at all-time scales between Climate, Coastal processes, Relative sea-level changes and Human activities. Positive sediment budgets set up local or regional regressive conditions and are commonly reflected by coastal accretion and the formation of depositional features, typically sedimentary prisms, deltas, tidal flats, beaches, offshore bars and dunes. Negative budgets originate transgressive erosional conditions resulting in beach retreat, land losses, flooding and salinization of coastal deposits, among other undesirable impacts (Figure 1.1).

Transgressive conditions do not necessarily result in beach destruction, since sandy coastlines like barrier islands are able to migrate onshore and avoid destruction in the case of free evolution and enough accommodation space (Kaufman & Pilkey, 1983; Pilkey, 1983). Obviously, future accelerated Sea-level rise resulting from climate change and/or coastal subsidence add a new dimension to the areal extension and rates of expected changes along much of the low coastal zones around the world, at times where human occupation of these areas is growing at unprecedented rates (Bird, 2010; WEF, 2015).

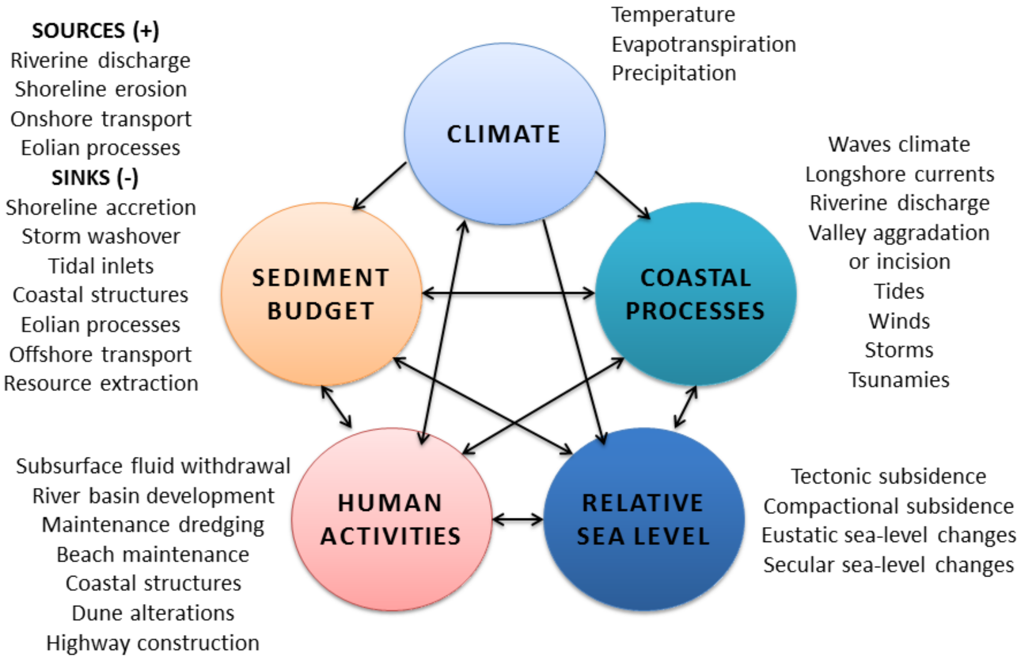


Figure 1.1. Factors affecting coastal environments. After Morton and Pieper (1977) and Williams et al. (1995).

Although its occupation by European conquerors and settlers began not before the XVI century, the magnitudes and consequences of much of the historical morphological changes along the Colombian seaboards are good enough to represent both scientific and practical interests. The dynamic character of all natural factors of Northwestern South America and the inappropriate development of the Colombian coastal watersheds have resulted in numerous critical cases of physical instability and strong environmental deterioration. Geological hazards and vulnerability related to flooding and shore erosion are growing rapidly in the Colombian seaboards, especially along the densely populated urban areas of the Caribbean coast main cities (Santa Marta, Cartagena, Turbo presently subjected to extensive flooding during high tides and/or heavy weather (Ortiz, 2012; Rangel-Buitrago & Anfuso, 2015); on the Pacific coast, main cities (Buenaventura, Bahia Solano, Guapi and Tumaco) and all the littoral villages are highly vulnerable to earthquake and tsunamis (AIS, 2009; Corporación OSSO-CVC, 2008; Correa, 1996; Correa & Morton, 2003; Herd et al., 1981; Posada, Henao, & Guzman, 2009). Strong environmental deterioration caused by shore erosion, waste disposal, agriculture, mining and pollution of coastal waters and soils are currently of primary interest in the environmental agenda of the country (INVEMAR, 2003; Olivero & Johnson, 2002). These facts urgently call for intensive research about the ecological evolution of the Colombian littoral zones from an anthropogenic point of view. The information about past trends and factors involved in the physical evolution of the different coastal types of Colombia is then necessary for predicting future trends and implement adequate coastal management strategies.

The purpose of this chapter is to illustrate the magnitudes and causes of some of the major historical morphological changes along the Colombian Caribbean and Pacific seaboards. Some of these changes have been of kilometric magnitudes and most of them can be easily identified by comparing shore contours and morphological features depicted in modern maps and remote sensing materials with those shown in some historical reliable charts dating back to the end of the XVIII century. Among the first reliable cartographic charts available are those produced by the Spanish Brigadier Francisco Fidalgo (The Fidalgo Expedition) along the Southern Caribbean Sea, including the coasts of Panama, Colombia and Venezuela. These charts were based on field work during the period 1792-1812 and have been fully recognized for their quality and accuracy (Dominguez, Salcedo, & Martin, 2012; Fuentes & Jaramillo, 2015). They can be also complemented with other ancient charts available for the main Colombian Caribbean deltaic zones and urban areas elaborated during the XIX century.

1.3. Main historical morphological changes along the central Caribbean coast of Colombia

Although noticeable geomorphological instability has been reported for numerous sectors between Santa Marta and Castilletes (Correa & Morton, 2003; DIMAR-CIOH, 2013; Posada & Henao, 2008; Rangel-Buitrago et al., 2015), the main historical morphological changes along the Caribbean are found along its central sector, here defined between the Magdalena river delta-Salamanca bar and the Sinú-Tinajones river delta, on the south westernmost part of the Morrosquillo Gulf (Figure 1.2). Coastal evolution of this zone has been extremely dynamic in historical times and has included both erosional and depositional events that have greatly modified the littoral landscapes.

1.3.1. General context

The tropical, mixed micro-tidal (40 cm tidal amplitude), wave-dominated Caribbean littoral of Colombia extends for about 1,700 km (scale 1: 100,000) between Punta Castilletes (Venezuelan border) to Cabo Tiburones, at the Panamá border, northern tip of The Urabá Gulf (Figure 1.2). The Caribbean Coast of Colombia is a physiographic region with medium diurnal temperatures of 28° - 30° C° and annual rainfalls varying between 300-600 mm in the north-eastern sector and 1,200-2,000 mm in the south-western part (IDEAM, 2010). Semi-desert conditions are found at the northern part of La Guajira peninsula, and a dry climate is found between the littorals of Santa Marta and Cartagena. Humid conditions are dominant along the Gulf of Morrosquillo area and the Sierra Nevada de Santa Marta Massif SNSM, the highest mountain in the world plunging directly to the sea and reaching its maximum height at Pico Bolivar (5,755 masl).

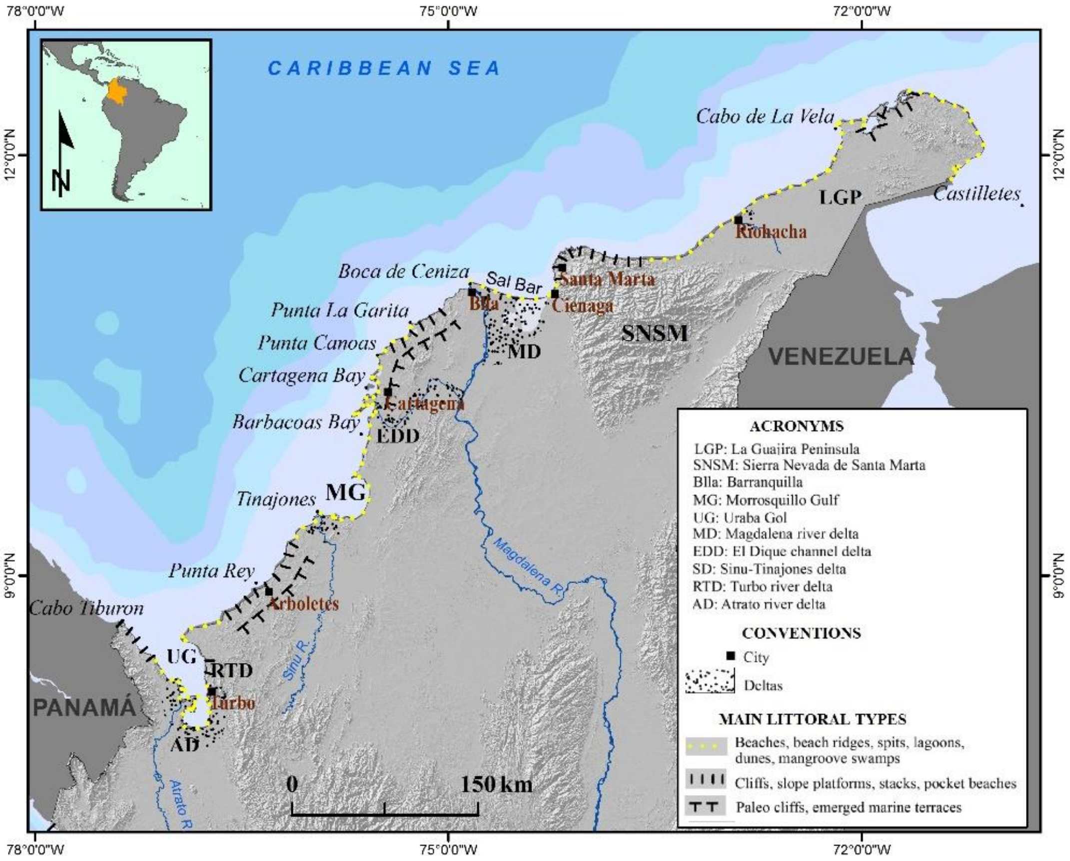


Figure 1.2. Location map and main morphological types of the Colombia Caribbean littoral.

Oblique, up to 7 Kt, NE-NW incidence of the trade winds (Alisios) on the Caribbean's shores generates high waves during summer time (November-April) which induces strong longshore currents and net sand transport in a SW direction along most of its length (INVEMAR, 2006). This condition is morphologically reflected by the dominant, S to SW orientation of spits and by the plain-view configuration of the z-bays form orientation. During the rest of the year, longshore currents are reversed by EW and SW winds and waves when sand transport has a northern component (Correa, 1990; DIMAR-CIOH, 2013; INVEMAR, 2006).

Except for the internal shores of the Morrosquillo Gulf, the littoral fringe of the southern Caribbean coast of Colombia between Ciénaga and the Urabá Gulf is entirely located on the Sinú belt, a tectonically active, fragmented Tertiary accretionary prism whose evolution has been strongly influenced by mud diapirism since Miocene times (Geotec Ltda, 2003; Vernette, 1985). Mud diapirism has been interpreted as one of the main controls of the sedimentation patterns, shelf topography and the occurrences and distribution of reefs along the southern Caribbean coast of Colombia (Carvajal, 2016; Carvajal & Mendivelso, 2011; Ojeda, Restrepo, Correa, & Ríos, 2007; I. Restrepo, Ojeda, & Correa, 2007; Shepard, Dill, & Heezen, 1968; Vernette, 1989; Vernette, Mauffret, Bobier, Briceño, & Gayet, 2011).

Of direct interest in the context, the historical activity of mud diapirs in the area includes major landscape modifications through, in many cases, violent extrusions of mud and gases both in the continental shelf and inland (Carvajal, 2016; Correa, 1990; Raasveldt & Tomic, 1958; Ramirez, 1959). Late Holocene relative changes in sea-level associated to mud diapirism, fault activity and neotectonism are evidenced along the Galerazamba - Cartagena area by emerged coralline terraces and marsh deposits located between 1 and 15 masl. These deposits have been radiometrically dated between 2,700 and 3,600 BP and interpreted upheaving varies between app 3.8 mm/year to 1.5 mm/year (Burel & Vernette, 1981; Carvajal, 2016; de Porta, Barrera, & Julia, 2008; J. I. Martínez et al., 2010; Page, 1983; Richards & Broecker, 1963; Vernette, 1985, 1989).

Main littoral types along the Caribbean seaboard reflect the inherent geology of each coastal strip and its Late-Holocene history and climate (Correa & Morton, 2003; DIMAR-CIOH, 2013; Posada & Henao, 2008). They range between steep-plunging cliffs cut on metamorphic and igneous rocks found at the SNSM, some short sectors of the Guajira peninsula and the Northwestern part of the Uraba Gulf, to the low-relief, Late-Holocene sandy and muddy deposits forming offshore bars, spits, beach ridge-lagoon complexes and large areas of mangrove swamps located on the Magdalena, El Dique channel, the Sinú-Tinajones and Atrato river deltas (Figure 1.2). Minor areas of beach ridge-lagoons and mangrove swamps are found in the embouchures of minor rivers of the Caribbean (Riohacha, Dibulla, Moñitos, Córdoba, Hobo, Mulatos) some of them regularizing the coastal indentations (plain view) in presently non-deltaic zones and small river mouths along the low-relief shores of La Guajira Peninsula and the Gulf of Morrosquillo. Longitudinal mobile dunes up to ten meters-high are found at the Caribbean coast of Colombia only to the north of Cartagena city where dry conditions, low relief, sand availability and the incidence of the Alisios facilitates its formation. Major dune zones are found at the Galerazamba area, the Salamanca bar (in front of the Ciénaga Grande de Santa Marta lagoon -CGSM-, east of the Magdalena delta) and the northern part of La Guajira Peninsula (DIMAR-CIOH, 2009a, 2009b; J. Gomez, Byrne, Hamilton, & Isla, 2017; khobzi, 1981; Posada & Henao, 2008; Raasveldt & Tomic, 1958).

1.3.2. Historical morphological changes along the Magdalena river delta shores and prodelta

The historical morphological changes along the shores and prodelta of the Magdalena river delta are the best available example of dramatic, short-term littoral changes induced by human actions. Current active and severe erosional trends were triggered along the coastline of the Magdalena river delta and surrounding shores as a direct result of the construction of the Bocas de Ceniza jetties (Figure 1.3). These structures were built to channel the Magdalena River's mouth and allow the entrance of big ships from the Caribbean Sea into the fluvial port at Barranquilla city. The first step in the construction of this 800 meter-long, parallel and rocky/concrete structures was finished in 1934, and the short-term results show strong modifications to the sediment balances of the zone (Alvarado, 2007; Koopmans, 1971). By intercepting the E-W net longshore drift along the delta's shore, they triggered an acute deficit of sand in the down-current direction, resulting in the erosion of all emerged and submerged sandy shoals west of the river. This included the Sabanilla barrier Island that in 1945 (7 years after the longshore disruption) was delineated as an erosional submarine sandy shoal in a photo interpretation made by Raasveldt and Tomic (1958) (Figure 1.3). Recent studies for the last 50 years of evolution of the coast southwest of Bocas de Ceniza have shown the progressive formation of newer and smaller depositional sand bodies to the south of the initial position of river shoals and bars (Anfuso, Rangel-Buitrago, Correa, & Finkl, 2015; JO Martinez, Pilkey, & Neal, 1990). The importance of mud diapirism and possible structural control on the orientation of these features has been argued by Anfuso et al. (2015).

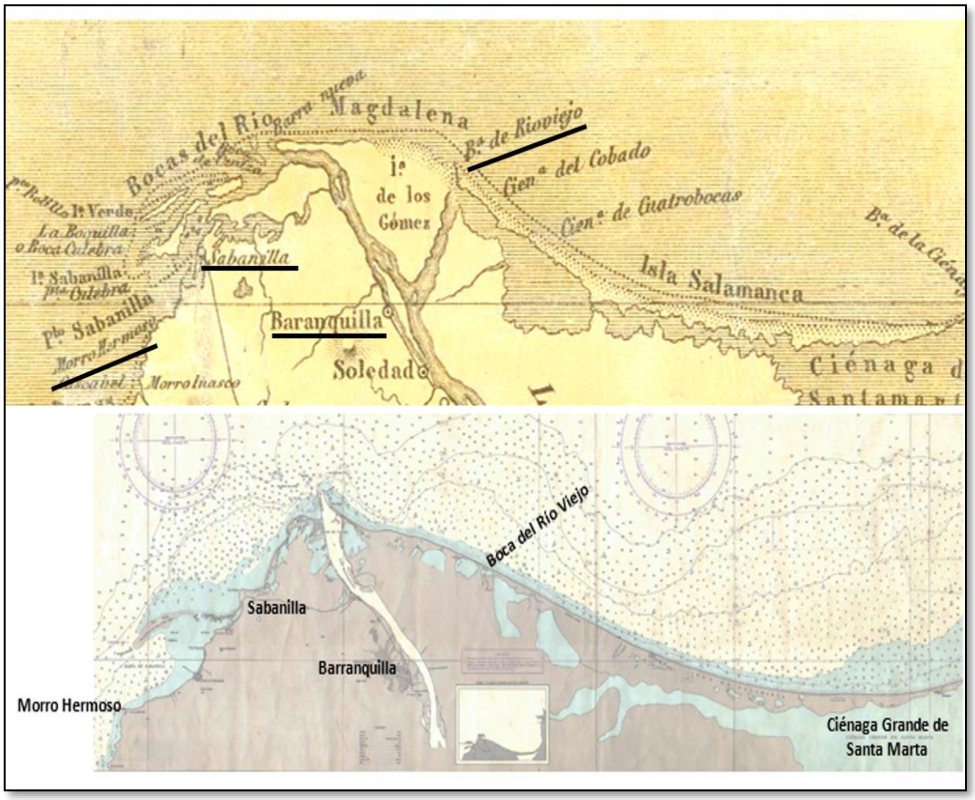


Figure 1.3. Magdalena river delta shores, 1852 and 1934. Upper: Magdalena river delta coastline and offshore bars to Puerto Colombia, including Isla Verde; chart published in 1852, taken from Comisión Corográfica y de orden del Gobierno General, por Manuel Ponce de León y Manuel María Carta corográfica del Estado de Bolívar, la Paz, Bogotá, 1864. Down: USS Nokomis Chart 5688, after hydrographical surveys data obtained during 1935-1936.

Coastal instability along the Magdalena delta front and nearby shores has not been restricted to sand imbalances along its shore areas and shallow platform, but also to deeper waters. Besides interfering with the East-West directed sand drift along the delta's shores, the jetties also concentrated the sand deposition (estimated in 30 x 106 m^3/year) just offshore of its ending points and induced strong conditions of instability on the delta submerged front (Laboratorio Central de Hidráulica de Francia, 1958). As a result, and coinciding with times of high discharge picks of the river (August and November-December), at least five submarine slides and turbidity currents occurred in the area between 1935 and 1963. Two of these slides (in 1935 and 1945) started near the shore and eroded 248 m and 500 m of the outer ends of the eastern and western groins respectively (Alvarado, 2007; Heezen, 1956; Koopmans, 1971). Turbidity currents followed the ancient Magdalena River channels and involved bathymetrical changes up to 200 m. They caused the rupture of several submarine cables located up to 24 km distant from the river mouth and at 1,400 m of water depth on at least five different occasions (Figures 1.4 and 1.5).

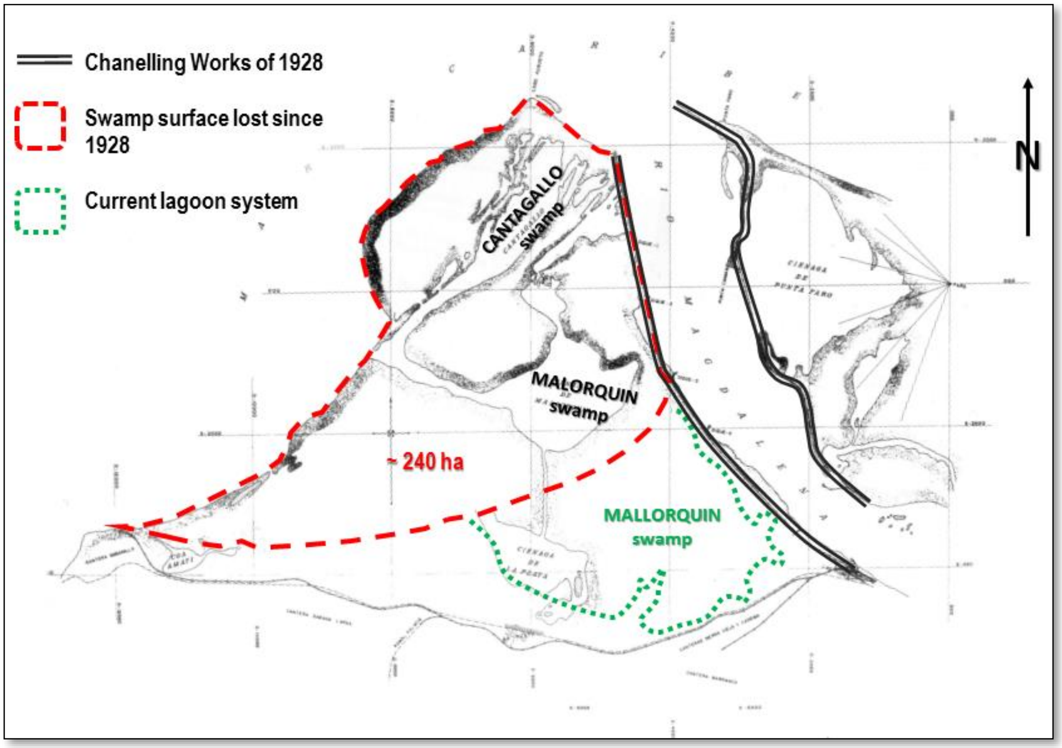


Figure 1.4. Comparison of shoreline configuration west of the Magdalena river mouth between 1928 and present, indicating the swamp surface lost since the construction of the channelling works of Bocas de Ceniza in red and the remnant of the lagoon system of the current delta in green. The historical map represents the progress of the channelling works at Bocas de Ceniza by 1928. Sources: Rico (1967).

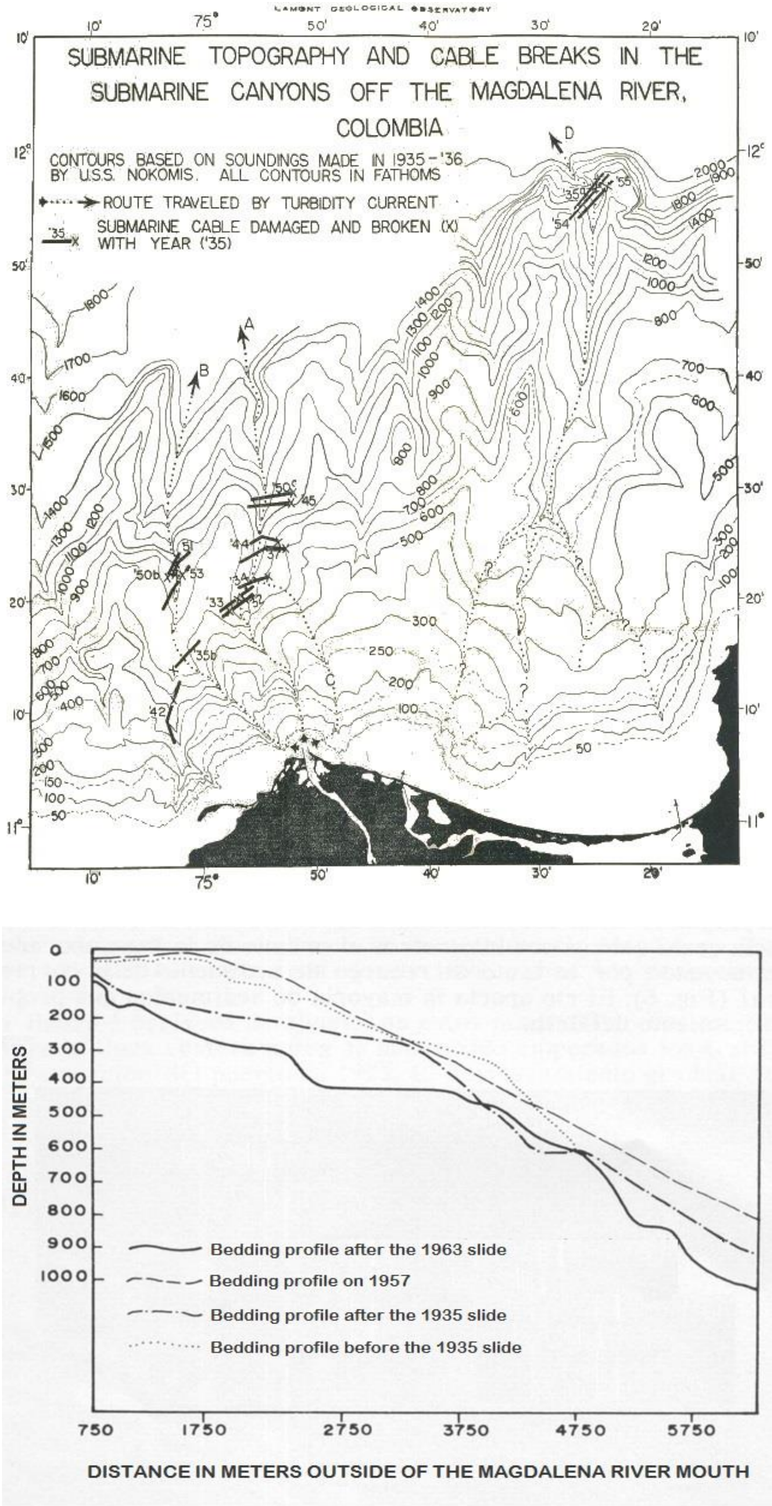


Figure 1. 5. Submarine slides at the Magdalena delta front. Upper: paths of submarine slides and location of cable´s breaks. After Heezen (1956). Down: submarine profiles changes along the Magdalena delta front after the 1935, 1953, 1957 and 1963 submarine slides; after Rico in Koopmans (1971).

1.3.3. Historical morphological changes between Galerazamba (La Garita point) and the Sinú-Tinajones delta.

South of the Magdalena delta area, the XVIII century configuration of the Caribbean littoral has been profoundly modified both by erosional and accretional trends involving kilometric modifications of the coastal contours. Most of the length of the central and southern Caribbean of Colombia is currently dominated by strong net erosional trends up to 1 m/year (40 m/year in some exceptional cases) due in part to the interruptions of the sand longshore drift by more than 600 hard coastal defenses. Negative littoral deficits of sediments are also produced by intensive sand and gravel mining dating back to the beginning of the last century (Correa, 1990; Correa & Morton, 2003; Posada & Henao, 2008; Rangel-Buitrago et al., 2015).

Most notorious, entirely naturally-induced morphological changes along the central Caribbean coincide with zones of active mud diapirism and are well illustrated between Barranquilla and Cartagena by the disappearance of the 10 km-length Galerazamba spit (Figures 1.6 and 1.7) and by the formation of the Isla Cascajo tombolo (Figure 1.8). This latter feature, with an area of 25 km² (measured on a Google Earth image of 2016) conforms a beach ridge-dune-lagoon complex capped in some places by fluvial deposits. Today it represents the surface of a sandy accretionary prism whose deposition was promoted by the strong wave diffraction of N- NE incident swells around the Isla Cascajo Island, in conditions of high sediment supplies. The maximum water depths at the shallow platform were of approx. 5.5 m according to bathymetrical surveys of the U.S.S. Nokomis made in 1934. Its formation initiated at an unknown date between 1792 and 1934 (Anfuso et al., 2015; Correa, 1990; Raasveldt & Tomic, 1958).

Figure 1.6. Historical coastline changes at Galerazamba (La Garita Point) and Isla Cascajo area, Barranquilla-Cartagena littoral from Brigadier Fidalgo chart made with field data from the end of the XVIII century. Current configuration of shoreline is depicted in yellow along with the conventions G: la Garita Point, IC: Cascajo Island, MV: Morro de La Venta Point, north-eastern extreme of Isla Cascajo tombolo, PP: Punta de Piedra point, southwestern extreme of Isla Cascajo tombolo.

On the western tip of the Morrosquillo Gulf, the deposition of the Tinajones delta is the most important event of historical littoral accretion on the entire Caribbean coast (Figure 1.9). The digging of drainage channels between the river's course and the sea at the Tinajones area facilitated the deviation of the main course of the Sinú River toward the sea in 1942-1943. This intervention induced the formation of the new delta, a lobular deposit presently with an overall area of 29 km² whose evolution has been described and interpreted in detail by several authors including Koopmans (1971), Troll and Schmidt (1985), Robertson and Chaparro (1998) and Serraron (2004). Impacts of these changes on the Cispatá Bay included drastic changes in the hydrological regimes that led to the salinization of 10,000 ha of rice crops.

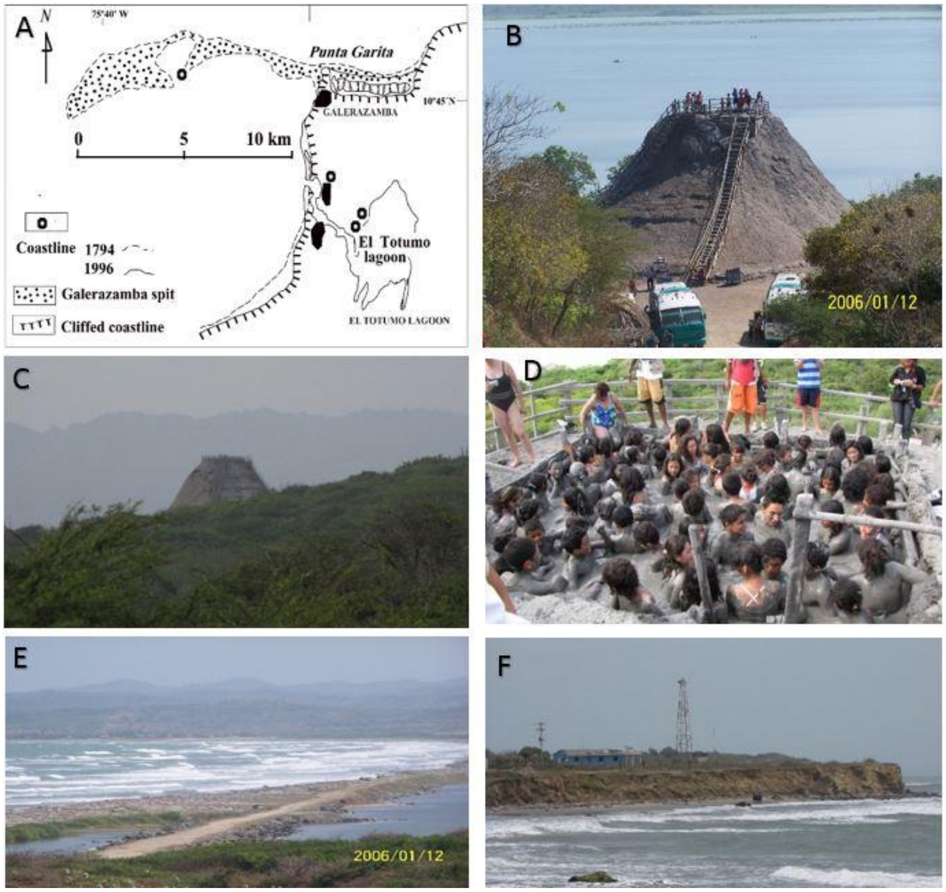


Figure 1.7. Galerazamba (Punta Garita) area coastline changes and geomorphological features. A) net coastline changes between 1794 y 1996, including the erosion of the Galerazamba spit and the noticeable cliff retreat to the south, in absence of the previous wave protection offered by the spit (from Correa, 1990); B) El Totumo mud volcano, view to the east (Photo by Ivan Correa; C) El Totumo mud volcano – 15 m-height, located on the northern flank of a 70 m-height diapiric dome (Photo by Ivan Correa); D) touristic use of the originally 1 m-wide el Totumo volcano crater (Photo by Ivan Correa); E) High energy dissipative beaches to the east of La Garita Point; F) Active, 7 m-height retreating cliffs south of Galerazamba (photographs by Ivan Correa). The Galerazamba area is famous for several violent explosive events of offshore and onshore volcanoes (at least three in the past century), the last being the explosion (2008) of the Pueblo Nuevo mud volcano that represented a serious risk for the inhabitants of Pueblo Nuevo village.

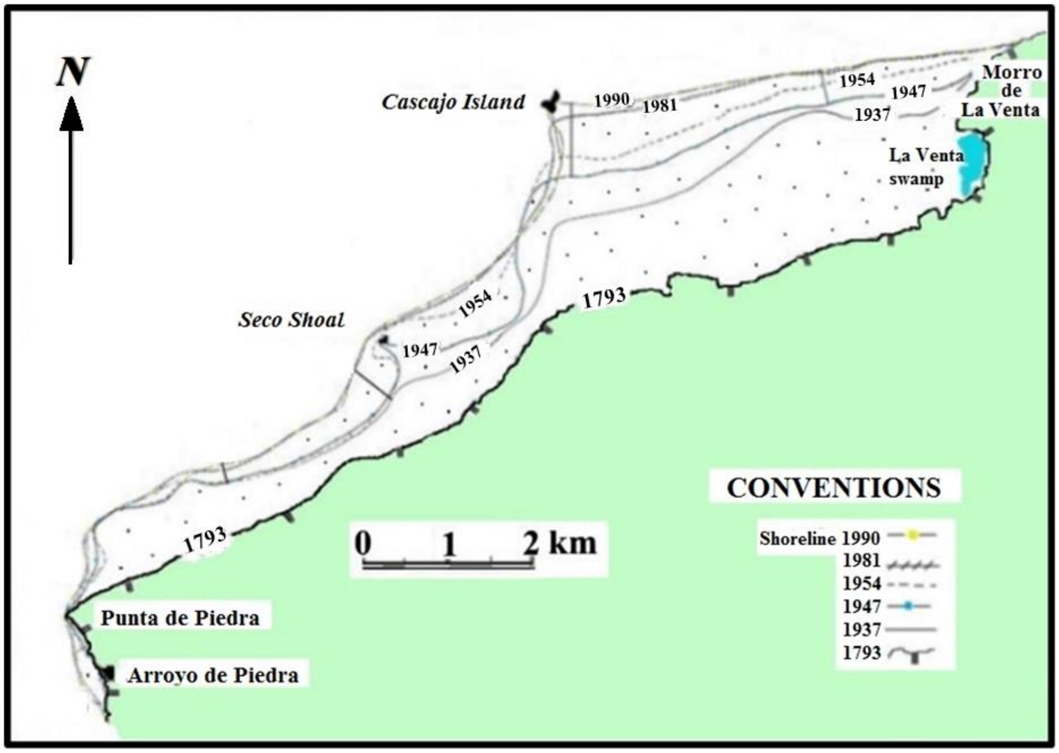


Figure 1.8. Isla Cascajo area coastline changes. Historical coastline changes between 1793 and 1990 showing successive coastline positions in 1793, 1937, 1947, 1954, 1981 and 1990 (After Correa, 1990). Tombolo formation initiated at some time between 1793 (Fidalgo's cliffed coastline) and 1937 (coastline depicted in the U.S. Nokomis navigation charts).

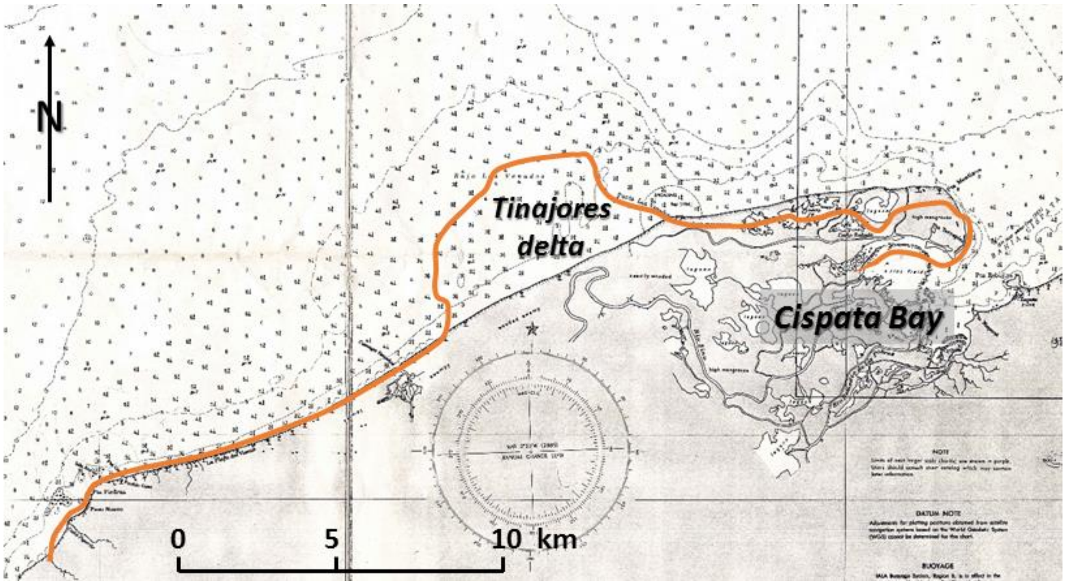


Figure 1.9. Tinajones delta and Cispatá bay. 1938 coastline shown on a nautical chart by the USS Nokomis based on surveys made in 1934

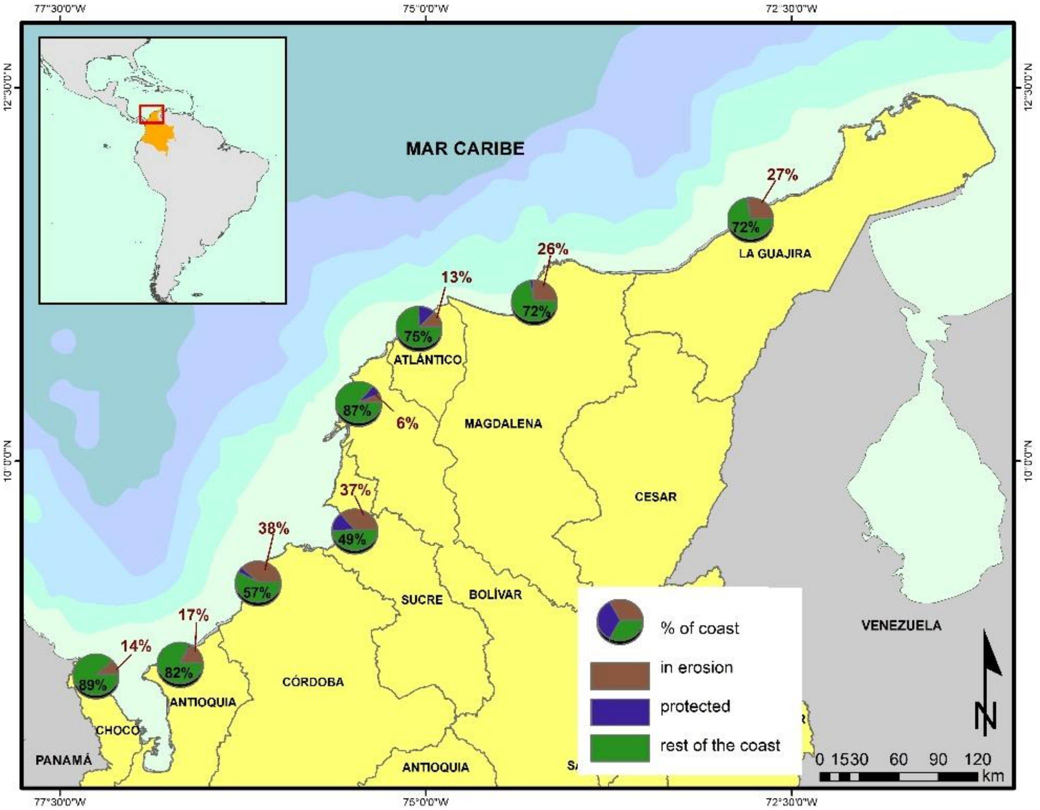


Figure 1.10. Proportion of shoreline in erosion and with protection by department of the Caribbean coast. Data from Posada and Henao (2008).

1.3.4. Infrastructure for Coastal protection

Approximately 22% of the total length of the Caribbean littoral are experiencing severe erosion (see Figure 1.10), and much of this trend is in part attributed to the interruption of sand drifts caused by coastal protection works (Guzman, Posada, Guzman, & Morales, 2008; Rangel-Buitrago et al., 2015). According to the estimations of Posada and Henao (2008), the departments with higher proportion of coastal erosion are Sucre and Cordoba, but Bolivar is the one with the highest amount of coastal structures. A total of 496 coastal defense structures have been inventoried along the Morrosquillo Gulf and the city of Santa Marta (Magdalena). It has been concluded that these structures allowed the preservation of some local areas but caused important imbalances in the sediment budgets of other sectors (Correa et al., 2005; Rangel-Buitrago et al., 2012)

Most rigid defenses (90% of the coastal protection structures according to Posada and Henao (2008) along the Caribbean coast have been constructed to face shoreline erosion without a long-term framework for proper territorial planning and relocation of endangered goods. Soft methods and defenses that replicate natural dynamics to recover sedimentary balance (artificial reefs, beach nourishment, dune regeneration, conservation and planting of mangrove or cliff drainage) have been implemented in only a few, localized areas. Examples of hard coastal defenses and types of materials used in Colombia are shown on Figure 1.11, where a crafted shore protection is depicted as a groin built up with “bolsacreto” or a resistant bag filled with a mixture of cement and sand.

Figure 1.11. Shore protection structures in the Caribbean littoral. Upper Sector of Marbella in Cartagena city (Bolivar), where a battery of groins is trapping sediments from the longshore drift towards the southwest (source: Esri Imagery); Down: Southern part of the Gulf of Morrosquillo (Sucre), where a sequence of breakwaters and T-shape groins that do not succeed in stabilizing the highly intervened sandy barrier in front of extensive mangrove swamps. Courtesy of Eafit University.

1.4. Main historical geomorphological changes along the Pacific Littoral of Colombia

Because of its low historical occupation and difficult accessibility, the morphological changes along the Pacific coast are much less documented and measured than those of the Caribbean coast. Available information indicates, however, a strong littoral instability evidenced by the rapid retreat of the Pacific deltaic coastlines as a short to long term effect of coastal subsidence. The influence of the human activities on the littoral changes and sediment budgets of the poorly engineered but strongly deforested and impacted by mining activities Pacific coast has not been studied at all.

1.4.1. General context

The mixed meso-macro tidal (tidal amplitudes between 2.5 and 4.5 m), Pacific littoral of Colombia extends for about 1,300 km (scale 1: 100,000) between Punta Ardita at the Panama border to Bahia Ancon, the southern tip of the Mira delta at the Ecuadorian border (Figure 1.12). The Pacific Coast of Colombia is one of the rainiest regions in the world, with medium diurnal temperatures of 28° - 30° C° and overall annual precipitation varying between 2,000 and 12,000 mm (IDEAM, 2016; J. Restrepo & López, 2008).

The Pacific coast has an approximated catchment area of 83,000 km² located on the coastal plain and on the western slopes of the Western Cordillera of Colombia. It is drained by more than 150 rivers, the most important of them being the San Juan River, the Patia River and the Mira River (Figure 1.12). The San Juan River at the central Pacific coast has a drainage area of 16,470 km² (352 km length) and carries a multiannual mean flow of 7,200 m³/s, with a sediment load of ~16.4 Mt/year. Further south, the Patia River (mean flow of 400 m³/s, 415 k- length) collects sediments from a watershed of ~ 23,700 km² and delivers an annual sediment load of ~ 21.1 Mt/year. At the southernmost part of the Pacific coast, the Mira River (catchment area of 9,530 km²; mean flow 871 m³/s) delivers a total sediment load of ~ 9.77 Mt/year (J. Restrepo, Kjerfve, Hermelin, & Restrepo, 2006) to the sea.

The Pacific coast of Colombia is a high seismic risk area characterized by the common occurrence of high-magnitude (M > 5) earthquakes, the best known being the 1836, 1868, 1906, 1979 and 1991 events (AIS, 2009; Corporación OSSO-CVC, 2008; Correa & Morton, 2003; Herd et al., 1981; JO Martinez & Lopez, 2010; Meyer, Mejía, & Velásquez, 1992; Ramirez, 1970, 2004; West, 1957). The earthquakes of 1906 and 1979 are proverbial in the zone because they generated at least two tsunamis waves up to 2.5 m high that flooded the low deltaic plains of the Patia and Mira deltas and caused general destruction along the coastline fringe and up to 30 km inland on terrains located well above the maximum tidal penetration, including the city of Guapi. For the northern Pacific coast, Ramirez (1970) reports the destruction of the Bahia Solano village by an earthquake occurred in

1970, and (Page and James (1981) reports the occurrence of several events of tectonic subsidence associated with the occurrence of large magnitude earthquakes north of Bahia Solano. Estimated coseismic subsidence values reported for these earthquakes range between a few cm to 1.6 m at the Southern coast of the Patia River delta (Herd et al., 1981). Inhabitants estimate coseismic subsidence values up to 2 m associated to the 1991 earthquake that hit the San Juan river delta and surrounding northern areas.

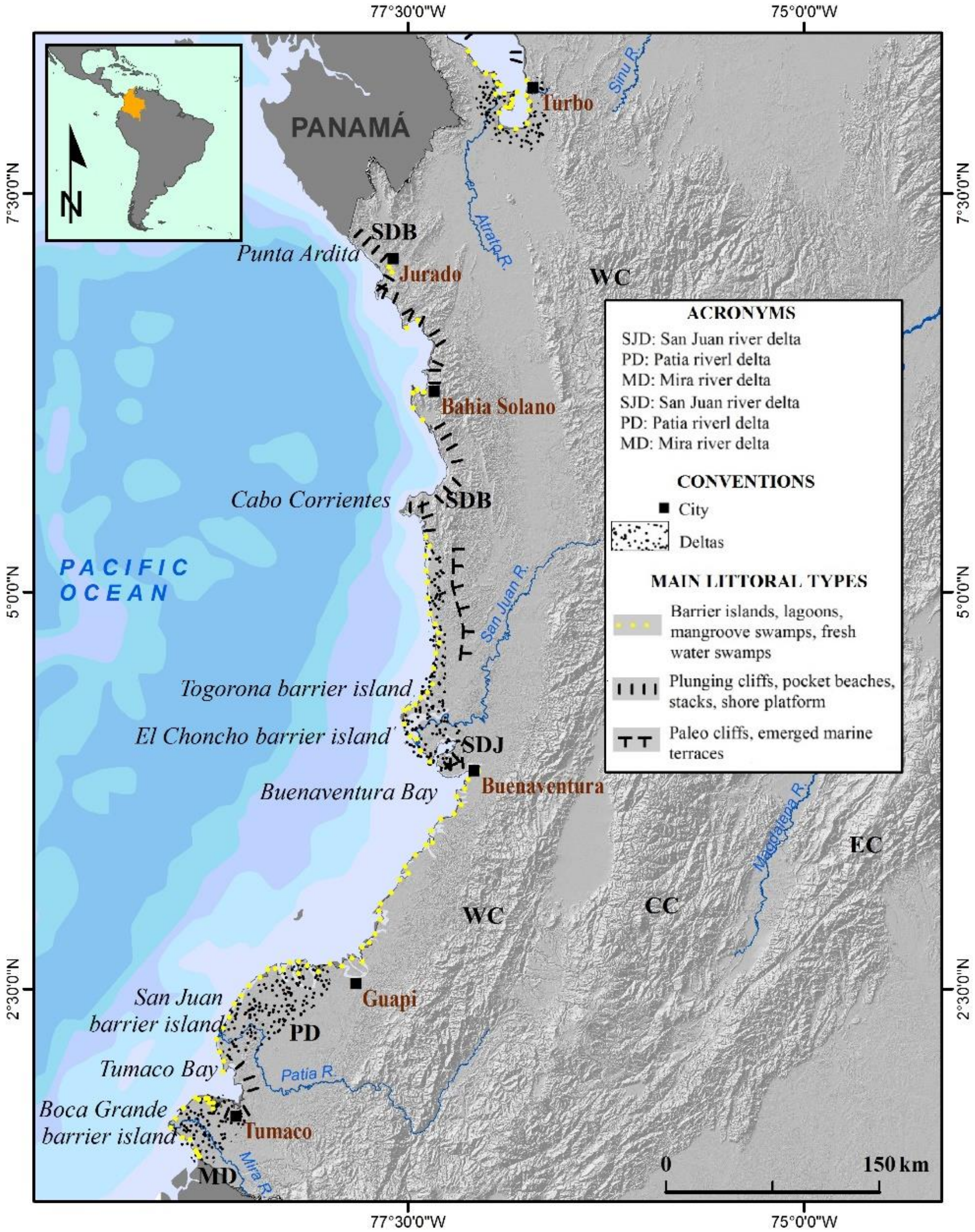


Figure 1.12. Location map and main morphological littoral types along the Pacific Coast of Colombia.

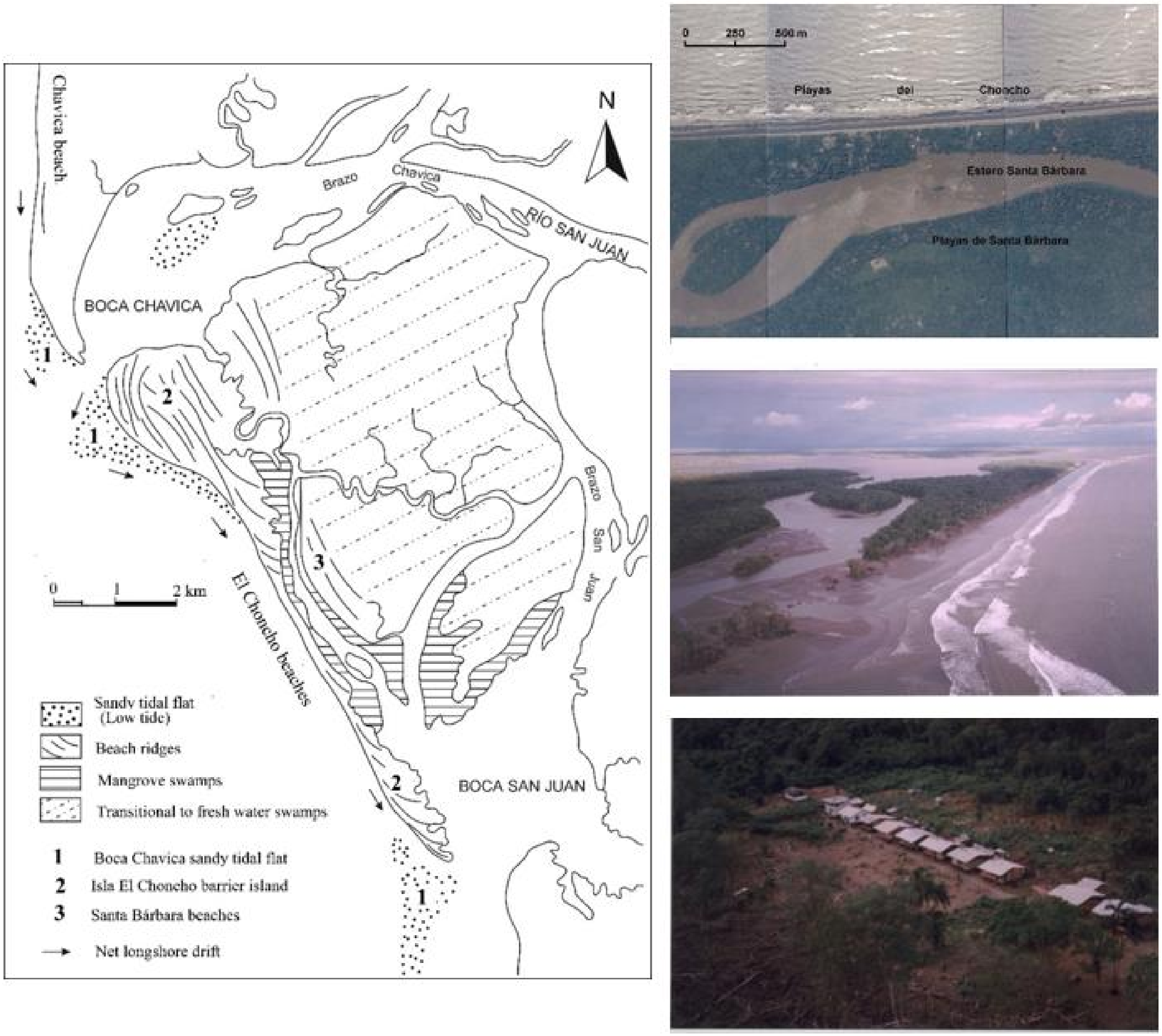


Figure 1.13. El Choncho barrier island. Left: geomorphological units of the southern lobule of the San Juan river delta; radiometric data taken from beach ridges besides Boca Chavica mouth and comparisons with ancient charts suggest that El Choncho barrier island initiated its formation by the end of the XVII century (From Morton and Correa, 2003). Upper right: El Choncho barrier island central part, photo by Ahmed Restrepo, 1996. Center right: aerial photograph illustrating the initial breaching at the central part of the barrier island, the same area illustrated above (photo by Iván Correa, 1997). Down right: The new Choncho after relocation to the ancient beach ridges - Santa Bárbara beaches - Photo by Iván Correa, November 1998).

From south to north, the main morphological littoral types along the Pacific coast are highly contrasting, varying between the structurally controlled rocky reliefs typical of the Serranía de Baudó range and the Buenaventura-Malaga bay (Figures 1.12 and 1.13) to the low Holocene depositional coastal prisms fronted by systems of barrier islands-estuarine lagoons, mangrove swamps and fresh water swamps (Correa, 1996; Correa & Morton, 2003; J. Martínez, González, Pilkey, & Neal, 1995; Smith, 1972; West, 1957). Because of the high tidal ranges, tidal penetration on the deltaic areas of the Pacific coast gets up to 30 km from the shoreline on the Patia River delta (H. Gomez, 1986; Van Es, 1975).

1.4.2. Historical coastline changes along the Barrier islands of the Pacific Coast

Best known examples of rapid coastal evolution along the Pacific coast are shown by the breaching of some of its major barrier islands along the shores of the San Juan, Patia and Mira deltas. Interpretation of the available data strongly suggest that the erosion and breaching of the already subsiding barriers island along this coast results from a combination of natural events, including sequentially, the deposit of extensive sandy tidal flats at the river's mouths followed by relative sea-level changes associated to coseismic subsidence and to temporal, 20 to 30 cm sea-surface positive anomalies associated to El Niño events (Correa, 1996; Correa & Gonzalez, 2000; Gonzalez & Correa, 2001; J. Martínez et al., 1995; Morton, Gonzalez, Lopez, & Correa, 2000; J. Restrepo, Kjerfve, Correa, & Gonzalez, 2002). At the El Choncho barrier island, subsidence caused by the November 19, 1991 earthquake was estimated at 20-30 cm, while at the San Juan de La Costa barrier island (Patia delta) hit by the November 12, 1979 earthquake, subsidence was estimated up to 1.6 m (Figures 1.13 and 1.14).

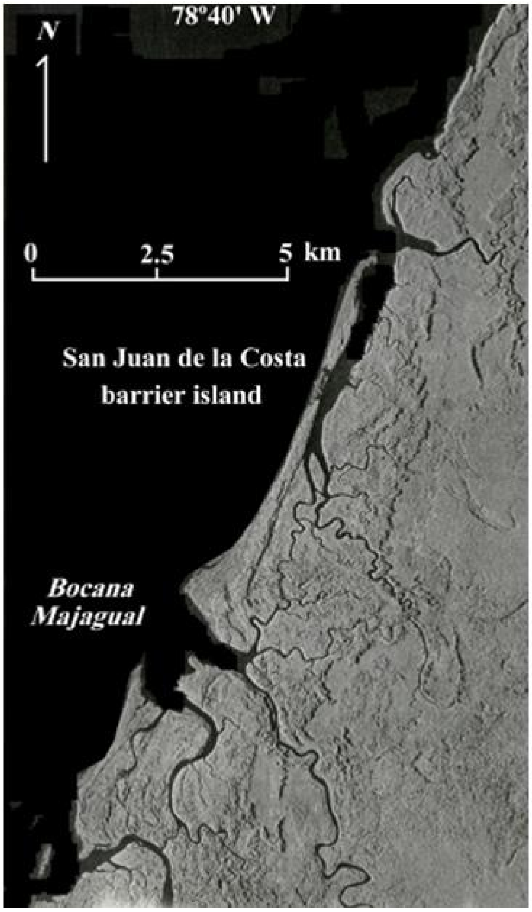


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Figure 1.14. San Juan de La Costa. Left: aerial photograph showing the beginning of the segmentation of the barrier island (taken from IGAC 1979). Right: the two concrete structures (small church) and school were the unique remnants of the two 2.5 m-high tsunami waves that hit the island in December 12, 1979. 250 inhabitants were drowned by this event (photo by Iván Correa, 1989).

1.5. Final remarks

The examples shown here of natural and man-induced changes in the budgets of sediments and the morphological responses along the coasts of Colombia illustrates only a part of its historical evolution. Strong erosional trends could also be reported all along the Caribbean littoral, more recent evaluations classified 48.3 (1,182 km) as suffering serious erosion during the period of 1980-2014 (Rangel-Buitrago et al., 2015). As a matter of fact, practically all the urban beaches of Caribbean cities are subject to erosional trends and are sustained with different success by engineering structures and/or beach replenishment projects often at exorbitant costs. The geological complexity of Colombian littorals points out a challenge for risk management at coastal zones and add great uncertainties to the integrated assessment of coastal risks associated to natural hazards (de Freitas, Smith, & Stokes, 2013; JM Martinez et al., 1994; Rangel-Buitrago & Anfuso, 2015; J. Restrepo & Cantera, 2013). However, probably much more important than the physical changes and their direct impacts on land losses and infrastructure, the environmental conditions of Colombian coastal ecosystems are rapidly deteriorating due to anthropogenic actions in the Andes´ catchments and adjacent coastal plains.

Besides the challenges imposed by natural drivers of morphological changes, coastal management in Colombia also faces the pressure of an accelerated population growth that comes along with poorly planned territorial development, especially in the Caribbean domain (Anfuso, Pranzini, & Vitale, 2011; Barragán & de Andrés, 2015). Human interventions linked to these developments, such as the jetties at Bocas de Ceniza in the Magdalena river mouth, or the diversion of natural currents within Tinajones area, have triggered negative effects on the stability of coastal terrain due to changes in the patterns of coastal dynamics and in the sub-oceanic geological processes that modify the coastal reliefs. These manmade induced perturbations have been responsible for the instability of coastal areas and the consequent deterioration of environmental conditions (Bernal, 1996; Correa et al., 2005; Gonzales, Urrego, Martinez, Polania, & Yokoyama, 2010; Rangel-Buitrago & Anfuso, 2015). According to Vilardy (2009), there were approximately 60,000 Ha. of mangrove when the high road Ciénaga-Barranquilla was built; a few years later, during the construction of the Palermo-Sitio Nuevo road, there was already a reduction of 5,000 ha. It wasn't until 1995, after the big expansion of agricultural frontiers into the Lagoon Complex, when the situation reached its most critical point because the mangrove was less than 30,000 ha.

The pressure imposed by uncontrolled human uses and activities causes coastal ecosystems to exceed their capacity for self-regulation, thereby increasing the vulnerability of coastal areas to natural threats of marine or terrestrial origin, such as storms, mud volcanism, river floods, mass movements and the sea level rise, among others (Anfuso et al., 2011; Botero, Fanning, Milanes, & Planas, 2016; Montes & Sala, 2007). The combined effect of linear, punctual and scattered human interventions over coastal ecosystems have induced serious problems in the Caribbean of Colombia. They include salinization of swamps and soils, mangrove death within the lagoons and habitat deterioration for aquatic and terrestrial species. Land colonization for agricultural purposes within swamps and lagoons territories involve the leaching of pesticides traces, heavy metals and fertilizers, which alter the physiochemical composition in the natural system and translate into pollution (Ibarra et al., 2014).

Therefore, unplanned territorial development represents another challenge for risk management and entails excessive costs of social and environmental protection for coastal populations and settlements (Cooper et al., 2009; INVEMAR, 2003; J. Restrepo, 2008). For example, local and national territorial authorities have been seen in need of managing more than 15 million dollars to counteract the coastal erosion triggered by the Magdalena river mouth channeling works (Heraldo, 2014). This intervention has been responsible for the loss of important ecosystem services related with beaches and lagoon systems affected, including resources for the economic support of local settlements, the discharge and recharge of aquifers, communications routs or flood mitigation (Anfuso et al., 2015).

The examples of coastal interventions cited in this chapter shows that negative effects derived from diverse types of coastal projects and activities have lacked adequate environmental evaluation, monitoring and control. Such insufficiency is due either to an absence of a regulatory framework or the reduced scope of Colombian legislation concerning all the possible coastal interventions that currently take place in the country (control and protection structures, buildings, docks, ports, marinas and navigation infrastructure, roads and bridges, thermoelectric and desalination plants, water pipes and drains, agricultural farms, dredging and mining or beach nourishment). An example of a lack of regulation corresponds to the described case of Bocas de Ceniza, whose channeling works initiated by 1922 before the existence of the first environmental law of the country (Code of Natural Resources of 1974).

Four decades later, environmental licensing processes in Colombia still don’t regulate the wide range of activities taking place in coastal areas. A review of the terms of reference for environmental impact assessments of projects or activities, published by the National Authority of Environmental Licensing in Colombia, comprises only two types of coastal interventions: maritime and fluvial harbors and structures for shore control and protection (EIA-TER-PC-1-01, 2011; M-M-INA-05, 2013; PU-TER-1-01, 2006; PU-TER-1-03, 2006). Although several highways in the country have been built near the coastline, especially on the Colombian Caribbean coast, terms of reference for road construction projects developed in 2013 do not include specifications regarding coastal conditions. This context reveals that there are still no specific criteria for projecting diverse types of interventions in the coastal environment and assess their associated impacts on coastal stability.

Given the complexity of the physical elements and the biological fabrics that intervene in geomorphologic evolution of coastal zones, the evaluation, monitoring and control of human interventions should consider how prone biotic and abiotic factors are to experience changes due to the perturbation induced by the construction, operation or dismantling of projects, structures and activities performed by man. This characterization can be defined as the physical-biotic susceptibility of a littoral territory regarding the morphological changes induced by the emplacement of coastal interventions. Such susceptibility comprises intrinsic and extrinsic factors that may give a partial representation of the resilience of ecosystems and the character of natural stressors exposed to human perturbations (Toro et al., 2012).

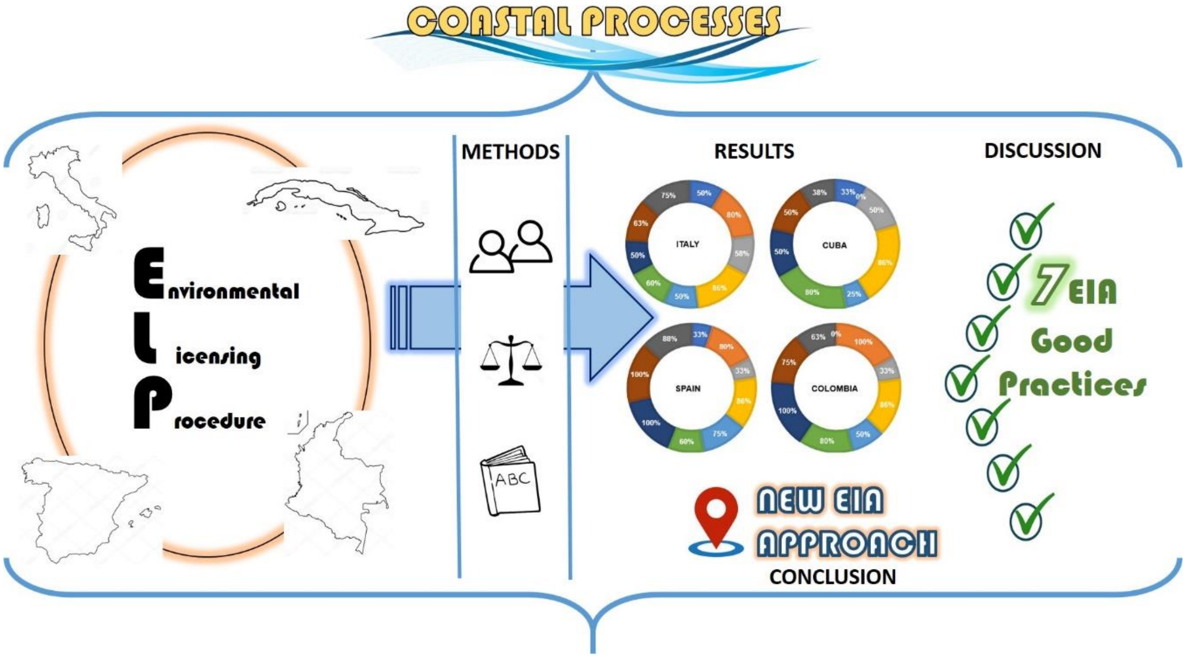
Extrinsic factors comprise of the forces inducing dynamic instability of littoral areas, such as the hydrodynamic, subaerial, geodynamic and human elements considered by Morton and Pieper (1977). This approach conceives of the property of physical-biotic susceptibility as a state of natural or artificially acquired exposition to morphological changes, in which previous human interventions play a significant role. Intrinsic factor refers to the ability of the natural system for recovering and toleration, which can be defined by the inherited geology of the littoral, along with indicators of health and functional integrity in coastal ecosystems (Heileman et al., 2006; Rangel-Buitrago & Anfuso, 2015). Sandy, rocky, marine and wetland ecosystems play a key role both as indicators of morphological evolutions and predisposition to unnatural perturbations.

Several studies at local and regional scales have been done regarding the natural conditions of the Colombian coasts, their evolution and their vulnerability to specific hazards. At regional scale, the Maritime General Directions, throughout the Research Center of Oceanography and Hydrography, have performed a physical-biotic characterization of the Colombian Caribbean coast (DIMAR-CIOH, 2009a, 2009b) and the Geomorphological Atlas of the Colombian Caribbean coast (DIMAR-CIOH, 2013). In addition, there are also two separate assessments of coastal vulnerability to the effects of the sea-level rise for both Pacific and Caribbean coasts, one developed by the Institute of Hydrology, Meteorology and Environmental Studies of Colombia and the other one by the Institute of Marine and Coastal Research "José Benito Vives de Andreis (IDEAM, 2001; INVEMAR, 2003).

Despite these studies of coastal characterization and vulnerability, there is no tool to recognize the susceptibility of coastal areas against coastal morphological changes that are further enhanced by the installation of civil works or infrastructure. These studies have focused mainly on natural hazards, leaving aside the adverse effect generated by human interventions, or considering it only as one more element in the general vulnerability assessment. Environmental licensing of coastal interventions in Colombia can be improved by institutionalizing adequate criteria in the assessment of the environmental factor that truly describe the intricate processes governing coastal dynamics. Therefore, it is pertinent to focus the analysis of physical-biotic susceptibility of littoral areas against the effects of coastal interventions, so that environmental licensing processes have a conceptual and methodological reference to reduce subjectivity in the environmental assessments regulated in Colombia (Toro, Requena, & Zamorano, 2010).

CHAPTER II

Seven Good Practices for the Environmental Licensing of Coastal Interventions: Lessons from the Italian, Cuban, Spanish and Colombian Regulatory Frameworks and Insights on Coastal Processes



2.1. Abstract

Environmental licensing is the regulatory procedure that enforces the environmental impact assessment (EIA) of human activities inside a given country. Despite worldwide acceptance of EIA as a valid tool, its application in coastal environments is still too diverse and limited regarding the specificity of the natural processes influencing the shore. This paper compares the Environmental Licensing Procedure (ELP) of four countries, focusing on the activities that could affect the coastal geomorphology. The acquisition and validation of information were done through interviews with EIA representatives in each country, who signalized the official documents of environmental licensing and coastal management to be considered in the documentary review. The results present those differences and similarities among ELP stages in each country, based on the principles of the International Association of Impact Assessment and the national documents analyzed. In sum, 59 interventions associated with human uses and activities in the coastal zone were compared according to the prescriptive character of the environmental licensing in Italy, Spain, Cuba and Colombia. The natural processes influencing coastal geomorphology were also analyzed within the technical criteria included in the official guidelines for the EIA, finding a generalized weakness in processes associated with geochemical courses on coastal environments. By way of discussion, seven good practices are illustrated, according to their pertinence to the impact assessment of the coastal zone: 1) The integration of screening and scoping; 2) Evaluation focusing on the environment rather than the intervention; 3) Binding the coastal zone delimitation; 4) Institutional articulation; 5) Accreditation of environmental consultancies; 6) Official guidelines by types of environment; 7) The integration of environmental geographic information. Finally, general conclusions to assist EIA practitioners operating in the four countries and recommendations to lead further research are provided, introducing a novel process-oriented approach for ELP.

2.2. Introduction

Despite environmental impact assessment (EIA) being widely accepted, the procedure regarding coastal interventions is not entirely homogeneous among different countries and even different regions within the same country (Li and Zhao, 2015; Zhang et al., 2013). As a demonstration, a compared analysis of the EIA regulatory framework in four countries, two European (Italy and Spain) and two Latin American (Cuba and Colombia), is presented in this article. Italy presents a federated system, while Spain is semi-centralized. The other two are centralized, but have different political ideologies. The issues addressed here include interventions which are not regulated but affect the coastal zone, and those which are regulated but disregard the importance of coastal processes. Consequently, this article seeks to identify, compare and synthetize good practices for improving a specific component of the EIA, the Environmental Licensing Procedure (ELP), from the regulatory framework of four countries exposed to numerous coastal interventions.

In fact, several human interventions are affecting coastal environments as built structures and land use changes derive into coastal instability, armoring, ecosystem malfunctioning and, in the main, disruption of the natural balance (Frihy, 2001; Cooper and Pilkey, 2012). Even though most coastal geomorphological changes are attributed to projects directly installed on the littoral, human transformation of watershed also plays an important role in the assessment (Anfuso et al., 2011; Restrepo et al., 2016). This situation exemplifies the highly dynamic and interconnected character of coastal environments, where natural flows of energy and materials from highlands, lowlands and marine areas overlap in space, as do their management challenges (Vallega, 1999).

In this context, coastal geomorphology results from the interaction among natural processes and human transformations acting on the environment (Alcántara et al., 2014; Correa et al., 2005). As Cavallin et al. (1994) state, the relationship of geomorphology with human interventions works in two directions: first, the morphometry of the locations needs to be suitable for a project or activity, but also geomorphological hazards can pose a risk to the integrity and functioning of interventions; second, the project's infrastructure and operation present threats to the geomorphological assets of the area and its surroundings. Likewise, coastal interventions have a strong geomorphological bias as they are framed by diverse processes influencing coastal morphology (i.e. Geological, Geochemical, Climatic, Eolic and Biogenic) (Pranzini, 2008; Masselink and Hughes, 2003). As a result, the measurement of impact on geomorphological resources, assets and processes could be a useful approach, albeit difficult to apply, for the environmental impact assessment and control (Rivas et al., 1997; Frihy, 2001).

In consequence, environmental licensing is a tool for controlling the effects of human interventions through a regulatory framework because legal and administrative arrangements are necessary to ensure the EIA legitimacy in every country (Wood C., 2003). According to the International Association for Impact Assessment (IAIA), the EIA is a "process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken" (IAIA & IEA, 1999). Meanwhile, the environmental licensing is understood as the documental or bureaucratic procedure that enforces EIA implementation. While environmental impacts are alike everywhere, regulations are restricted to national jurisdictions, and every country has its own particularities and limitations. For instance, the Colombian EIA regulation has been reported as ineffective due to a limited scope, inadequate administrative support and insufficient control mechanisms (Toro et al., 2010). Meanwhile, the longest administrative timing among European countries has been reported in Spain, where the scope definition of Environmental Impact Statements (EIS) has been voluntary since 2013 (Fuentes-Bargues, 2014; Enríquez-de-Salamanca et al., 2016). On the other hand, the decision making during environmental licensing procedures in Italy faces difficulties in transparency and effectiveness, which have led to strengthening mechanisms for proactive public participation and the provision of official guidelines (Bassi et al., 2012; Del Furia and Wallace-Jones, 2000). Lastly, the experience in EIA procedures in Cuba is rarely found in the scientific literature, however, the regulatory framework of this country presents an additional compelling argument for this paper, regarding the definition of coastal interventions.

Among the four countries, Cuba is the most explicit when determining coastal interventions. The Decree-Law 212/00 distinguishes at least 15 activities or facilities typical of the coast, which means those whose location cannot be other than the coastal zone (article 15). The Spanish coastal law (2/2013) also refers to a similar categorization by singularizing three types of interventions: creation and regeneration of beaches, promenades, and wastewater treatment facilities (article 44). The definition of coastal interventions in Italy is not explicit in the legal code, although a thorough document was recently prepared by a group of national experts to establish clear guidelines for assessing erosive phenomena and their environmental aspects (MATTM-Regioni, 2017). Furthermore, guidelines related to the protection of coastal habitats in the Liguria Region (Italy) distinguish nine types of coastal works and four types of coastal activities within the criteria for environmental protection. On the other hand, Colombia does not make such a distinction despite having two national policies for coastal areas (CCO 2007; MMA 2000).

The former precisions indicate distinct levels of awareness in the importance of coastal environments among the four countries. Still, none of them incorporate coastal interventions as a category within the administrative structure of the environmental licensing. This reveals a weakness in conventional EIA procedures, as the assessment concentrates on interventions and omits the specificity of the socio-natural environment. Given the inter-connected character of coastal environments, many interventions outside coastal boundaries still influence their morphology. Therefore, coastal interventions hereafter would be understood as all types of interventions affecting the coastal zone.

Lastly, many studies comparing countries use EIS as the contrasting subject through documentary review of study cases for specific types of interventions (Barker and Wood, 1999; Canelas et al., 2005; Bassi et al., 2012). For example, Guerra et al. (2015) analyze the need for implementing a mandatory EIA procedure for three types of marine interventions in Portugal through the comparison of 12 EIS's within seven countries with important maritime commercial zones. This kind of comparison is only possible when case studies are very specific or narrow because the universe of human activities and types of environments is too broad for a single research project. On the contrary, the comparison made here is focused on EIA legal codes, analyzing the Environmental Licensing Procedure (ELP) and Terms of Reference (ToR) for EIS preparation within geomorphological criteria addressing coastal processes. Finally, the conceptualization of good practices was inspired in the conceptual approach of Morgan (2017), who defines best practices as a form of knowledge used for specific ends and recognizes the character of best practice materials as narrative (examples and case studies), institutional (legal and administrative processes), or technical (substantive and practice-focused).

2.3. Methods

Stemming from the heterogeneity of the ELP of coastal interventions in the four countries analyzed, semi-structured interviews were conducted in the period from April to October 2017 with representatives of Italian, Spanish, Cuban and Colombian public administrations along with other agencies engaged in the ELP at various levels. A total of 19 interviews were conducted on representatives of public administration both at the national and regional government level, and representatives of scientific research bodies advising EIA procedures. Appendix II-A shows the full list of interviewed organizations with a brief description and reasons for the choice.

Because of their role or involvement, these people were expected to give the full picture of the current legal and policy practices, and the challenges for environmental licensing in their respective competencies. The topics of discussion in the interviews were:

a. Their role within the institution.

b. Competencies and activities within EIA in the coastal environment.

c. Technical criteria for validating project's influence areas and characterizing the environment

d. Existing regulations and guidelines to orient environmental licensing and coastal management practices.

e. Information systems designed for EIA procedures and monitoring criteria for project's follow-up

f. Existing challenges or good practices related to the EIA and follow-up of projects and human activities.

Information coming from the transcribed interviews was integrated with other documentary evidence, such as legal acts at the international, national and regional levels, other types of policy documents (e.g. local plans and programs), and official guidelines for EIS elaboration. The EIA representatives interviewed in each country signalized the official documents of environmental licensing and coastal management to be considered in the documentary review. The whole review was registered in matrices to reconstruct practices in ELP and coastal management. Appendix II-B gathers all documents reviewed.

For the comparative analysis, the flow of the procedure in the environmental licensing of each country was extracted from their respective legal codes. Furthermore, types of coastal interventions under ELP in each country were analyzed according to the prescriptions established in their respective regulations. An additional comparison was made from the guidelines formulated and adopted by each country, circling around technical criteria for environmental characterization within the elaboration of the EIS. The guidelines used for this comparison correspond to projects or activities to be emplaced on the shoreline, such as shore protection structures, beach nourishment, dredgings and ports. This approach was selected to enrich the relation of technical criteria with the natural processes influencing the coastal morphology, using Prothero and Schwab (2013), Pranzini, (2008) and Morton and Pieper (1977) as conceptual references. Finally, the discussion regarding good practices for the environmental licensing of coastal interventions is based on EIA materials of institutional and technical character among the four countries (Morgan, 2017).

2.4. Results and analysis

2.4.1. Environmental licensing procedures

The conceptual reference used for comparing the stages of environmental licensing among countries are the operating principles of EIA best practices, defined by the IAIA (IAIA & IEA, 1999). Seven of the ten operating principles were considered common stages of the licensing procedure, using a specific flowchart symbol for each stage (Figure 1.1). The other three principles (Impact analysis, Mitigation and impact management, and Evaluation of significance) were gathered under the label Valuation of environmental impact, since they are not considered a procedure stage themselves. The shape and color in the flowchart of the IAIA are the references to recognize the analogous stage followed by each country, as well as the indication of the order in which the EIA takes place. The stages for each country were determined by the recognition of the IAIA practices, the name of specific procedures and the responsibilities of parties involved in each country as specified in Appendix II-C.

The Cuban procedure comprehends only five of the reference stages, within which scoping, EIS preparation and follow-up are distributed in two stages each, while screening and alternative examination stages are not included. The two stages of EIS preparation take place in different moments because some environmental licenses do not require an extended EIS; therefore, this second study is requested only when the area of interest is not widely characterized with the former EIS's or the complexity of the project requires it. The ELP in Spain presents a similar configuration to the Italian flowchart mainly because both countries are bound to apply the European Union Environmental Impact Assessment Directives (2011/92/EU and 2014/52/EU). Last, the Colombian flowchart comprehends all the IAIA stages except the screening, because there is no structured procedure to decide whether certain interventions require undergoing a full EIA procedure or not. Instead, the licensing procedure in Colombia starts with the environmental alternative diagnosis, which is a separate environmental analysis to select the alternative that must apply a conventional EIA.

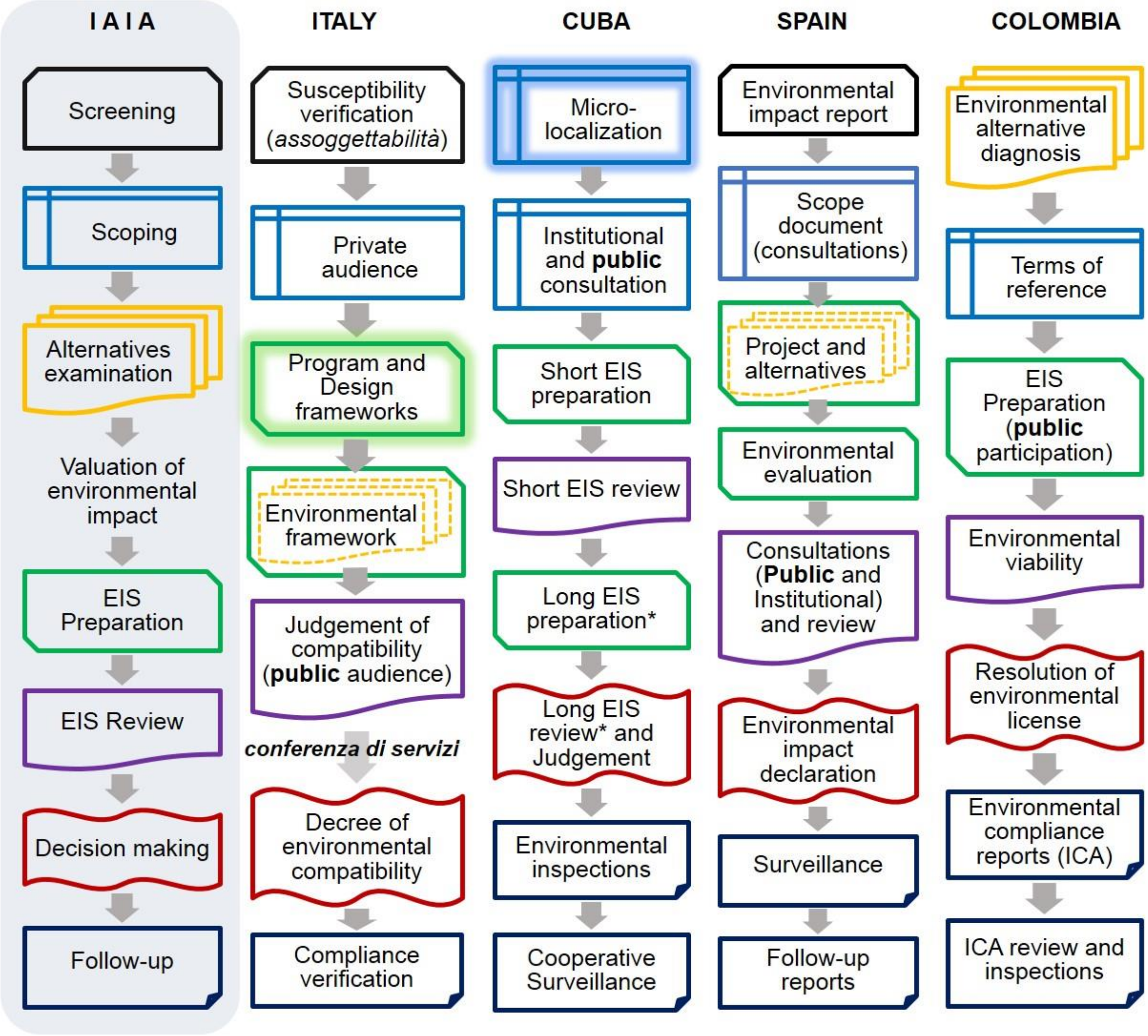


*Figure 2.1. Licensing procedure in Italy, Cuba, Spain and Colombia within the IAIA framework. (*Stages that take place only if the environmental authority requires it)*

In addition, there are some features in Figure 2.1 representing similarities among the four countries. Two highlighted figures in the flowcharts of Italy and Cuba indicate that both countries incorporate the same practice of articulating the proposed intervention with territorial planning strategies (i.e. urban, coastal, basin). A second feature emphasized is the dotted lines within the stages of EIS preparation at Italy and Spain, indicating that the examination of alternatives is inside the structure of the EIS documents in both countries. Finally, all of the flowcharts stress the practice of consulting the public or communities concerned by using bold letters in the stage of each procedure where it takes place or is more relevant.

2.4.2. Types of interventions subjected to environmental licensing

Coastal interventions and their compliance with the ELP in each country are summarized in Table 2.1, according to the competence level and procedure complexity indicated in the legal codes. The structure of coastal uses and activities proposed by Botero et al. (2014) was adapted to categorize the main types of projects that can be emplaced on the coastal zone or can influence coastal processes even outside the shoreline (i.e. River basin). The distinction between the national and regional competence of environmental licensing depends on certain characteristics of the project or activity. Therefore, Table 2.1 marks the shared competence with the letters representing both national and regional, and differentiates the screening stage with the asterisk on the corresponding competence. As an example in Italy, the type of intervention "thermoelectric plants", included in the annexes of the Italian Decree 104/2017, reveals that thermal plants with total power higher than 300 MW are subject to national competence. Meanwhile, plants with total power between 300 and 150 MW go under regional competence, and those between 150 and 50 MW follow a national screening.

Table 2.1. Type of intervention in the coastal zone subject to EIA procedures in Italy, Cuba, Spain and Colombia

Intervention with effects on the coastal zone		IT	CU	SP	CO
Edifications	Low-density settlements	R*	Ø	N*/R*	Ø
	High-density settlements	Ø	R	Ø	Ø
	Palatial settlements	Ø	Ø	Ø	Ø
	Luxury settlements	Ø	Ø	Ø	Ø
	Sun and Beach Tourism	R*	R	N/R	Ø
	Military installations on land	R*	Ø	Ø	Ø
Works of shore protection and control	Breakwaters and artificial reefs	**R***	Ø	**N*/R***	**N**/R
	Groins	**R***	Ø	N*/R*	**N**/R
	Walls	**R***	Ø	N*/R*	**N**/R
	Walks and ridges	Ø	Ø	Ø	**N**/R
	Beach nourishment	**R***	Ø	**N*/R***	**N**/R
Marine navigation and facilities	Inlet navigation channels	Ø	Ø	Ø	Ø
	Public Docks	Ø	Ø	Ø	Ø
	Luxury settlement with pier	Ø	Ø	Ø	Ø
	Sun and beach tourism with pier	Ø	R	Ø	Ø
	Deepwater ports without shelter	N*/R*	N	N/R	**N**
	Shallow water ports without shelter	N*/R*	N	Ø	R
	Sheltered ports	N*/R*	N	N/R	**N**
	Fishing ports	Ø	N	N/R	**N**
	Naval military installations	Ø	Ø	Ø	Ø
	Internal Maritime Transport	N*/R*	Ø	N/R	Ø
	Marinas	N*/R*	N	Ø	Ø
	Cruise tourism	N	Ø	Ø	Ø
Linear infrastructure	Roads, double roads, highways, bridges	N/R*	R	N*/R*	**N**/R
	Railways and facilities	N/R*	R	N*/R*	**N**/R
	Tunnels	Ø	Ø	Ø	**N**/R
	Airports and runways	N*/R*	N	N*/R*	**N**/R
	Electric lines and facilities	N*/R*	R	N*/R*	**N**/R

	Basic sanitation pipes	N*/R*	R	N*/R*	Ø
	Conduction of fluids through pipelines	N*/R*	N	N*/R*	**N**
Basic sanitation facilities	Desalination plants	Ø	Ø	N*/R*	Ø
	Solid waste exploitation and disposal	R*	R	N*/R*	**R**
	Submarine emissary	Ø	Ø	Ø	Ø
	Wastewater treatment plants	R*	Ø	N*/R*	R
Extensive land use and livestock	Farming	R*	N/R	N*/R*	Ø
	Golf course	Ø	N	Ø	Ø
	Mariculture	Ø	N/R	Ø	N/R
	Aquaculture	R*	N/R	N*/R*	N/R
	Thematic parks and camping	R*	Ø	N*/R*	N
Extractive activities	Exploration and mining	N/R*	N/R	N*/R*	**N**/R
	Exploration and extraction of hydrocarbons	N*/R	N	N*/R*	**N**
	Marine dredging	Ø	Ø	N*/R*	**N**/R
	River dredging	Ø	Ø	N*/R*	**N**/R
Drainage basin alterations	Transfer of basins	N/R*	R	N*/R*	**N**/R
	Underground water movement	R	Ø	N*/R*	Ø
	Irrigation districts operation	R*	R	N*/R*	**N**/R
	Changes in land use	Ø	R	N*/R*	Ø
	Modification of channels	Ø	Ø	N*/R*	**N**/R
	Dams and reservoirs	N/R	R	N*/R*	**N**/R
	Installations in fluvial causes	Ø	Ø	N*/R*	N/R
	Hydroelectric terminals	N/R*	Ø	N*/R*	R
Industrial and energy installations	Offshore platforms	Ø	Ø	N*/R*	Ø
	Geothermal plants	N	Ø	Ø	N/R
	Wind power plants	N/R*	Ø	N*/R*	**N**/R
	Solar energy plants	Ø	Ø	N*/R*	Ø
	Transformation and storage of fossil fuel	N/R*	N/R	N*/R*	**N**
	Manufacture	N/R*	N/R	N*/R*	**N**/R
	Geological storage	N*/R	Ø	N*/R*	Ø
	Thermoelectric plants	N*/R	N/R	N/R	**N**/R
∑ Interventions under either competence for EIA		21	7	41	24
∑ Interventions under national competence for EIA		2	9	-	7
∑ Interventions under regional competence for EIA		15	12	-	4
∑ Interventions of non-compulsory national EIA		36	43	18	28
∑ Interventions of non-compulsory regional EIA		23	40	18	31
∑ Interventions subject to national screening		13	-	35	-
∑ Interventions subject to regional screening		30	-	35	-

IT = Italy; CU = Cuba; SP = Spain; CO = Colombia; N = national competence; R = regional competence; Ø = not licensing required. *= Project subject to a screening for the national or regional competence; bold letters mean interventions with ToR or guidelines.

Total sums in Table 2.1 show that 36% (n=21) of coastal interventions undergo an ELP at a national or regional level in Italy, while another 36% are not under compulsory EIA or must follow an EIA by either competence exclusively (29%; n=17). Regarding Cuba, 12% (n=7) of interventions can be processed at a national or regional level, while the 36% (n=21) must undergo an ELP exclusively under one competence, being the majority at the regional level. The Spanish regulation makes no explicit distinction regarding competence level because such distribution depends on the sectoral body that confers the utmost authorization; therefore, 69% (n=41) of intervention are considered under national or regional competence, while the remaining 31% (n=18) are exempt of ELP. Lastly, Colombia sums 41% (n=24) of interventions regulated by either national or regional level, whereas 19% (n=11) are subject to an exclusive competence, being the majority at the national level; the remaining 40% (n=24) are exempt from environmental licensing. Briefly put, Spain has the highest percentage of types of interventions under the ELP, closely followed by Italy and Colombia, while Cuba presents the highest proportion of projects or activities exempt from ELP.

An additional analysis regards the coverage given by the EIA regulations within gross categories of coastal interventions. Percentages pictured in Figure 2.2 refer to the portion of interventions subject to ELP by category in each country. This means, for example, that three out of a total of six types of interventions in the category of *Edifications* are subject to environmental licensing in Italy, comprising coverage of 50%. In the same category, Cuba and Spain each equal 33% of the interventions regulated, all sharing the typology of 'sun and beach tourism' with Italy. Such projects in particular are associated with important impacts on the coastal zone, especially when poor land planning is also reported (Davenport and Davenport, 2006; Burak et al., 2004; Jennings, 2004). On the other hand, Colombia makes no direct mention of these types of edifications, despite the increasing amount of real estate developments and resorts along the Caribbean Coast in the last years (Cochero and Manjarrez, 2014; Rangel-Buitrago et al., 2012). It is worth mentioning that Spain and Italy present differences even though they both transposed the same EU directives, meanwhile Colombia and Cuba are similar despite holding different political ideologies.

The category of interventions about *shore protection and control* presents the highest regulation coverage in Colombia, the second highest in Italy and the third highest in Spain. This great level of awareness is consistent with the extensive lists of impacts (such as coastal armoring, intensification of erosion processes or deterioration of coastal scenery) associated with such interventions, (Pranzini et al., 2015; Rangel-Buitrago et al., 2017). Meanwhile, Cuba includes none of this intervention in their environmental licensing framework, since shore protection structures are considered environmental contraventions (Law 200/1999). Moreover, Cuba is the only country that includes golf courses in the ELP, which are common interventions in coastal areas, also linked to sea, sand and sun tourism.

On the other hand, interventions in the category of extractive activities are included in all four countries, and their influence on coastal processes is when they trigger subsidence trends (Morton and Pieper, 1977). Regarding the category of *Drainage basin alterations*, Spain is the one with full coverage, followed in order by Colombia (75%), Italy (63%) and Cuba (50%). Although interventions in this category tend to be geographically far from the coastal zone, they matter due to the link of physical processes modeling watersheds. Finally, the category of *Industrial/energy installations* is also barely associated with effects in the coastal zone unless the intervention is emplaced directly in this environment, which is a very probable situation. Their coverage in the EIA regulation of Italy, Spain and Colombia is above 50%, while Cuba is below this threshold.

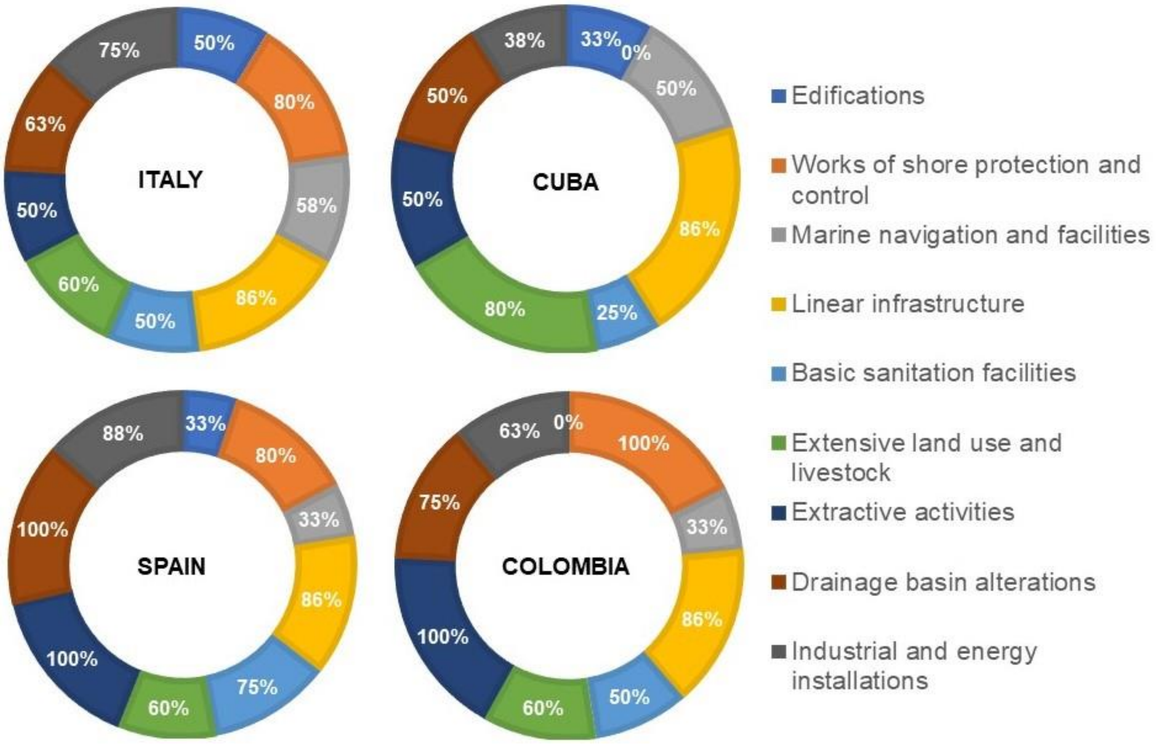


Figure 2.2. Proportion of interventions with an effect on the coastal zone by country and category.

2.4.3. Criteria for characterization of the coastal environment

Perhaps one of the major decisions within the environmental licensing is to define which criteria must be used to characterize the natural system. Stemming from the review of the regulatory framework and technical guidelines for EIS preparation, a detailed categorization of criteria influencing processes linked with coastal morphology was done, and several findings were extracted and represented in Figure 2.3. Appendix II-E gathers the resulting categorization in the four territories with reference to the guidelines reviewed in each one. Some criteria may be found in more than one process because criteria description and reference to their controlling mechanisms often relates to several kinds of processes. Cuba is not included in the comparison because, unlike the other countries, environmental authorities have not formulated or adopted official guidelines for EIS preparation. Additionally, the Italian region of Liguria was included in the analysis as a separate territory since their own guidelines are different from the ones adopted by the national authority. This was not the case for the other two Italian regions interviewed (Emilia-Romagna and Tuscany), whose authorities refer to the same national guidelines prepared by ISPRA[1], the technical and scientific advisor of the Italian Ministry of Environment regarding EIA competences.

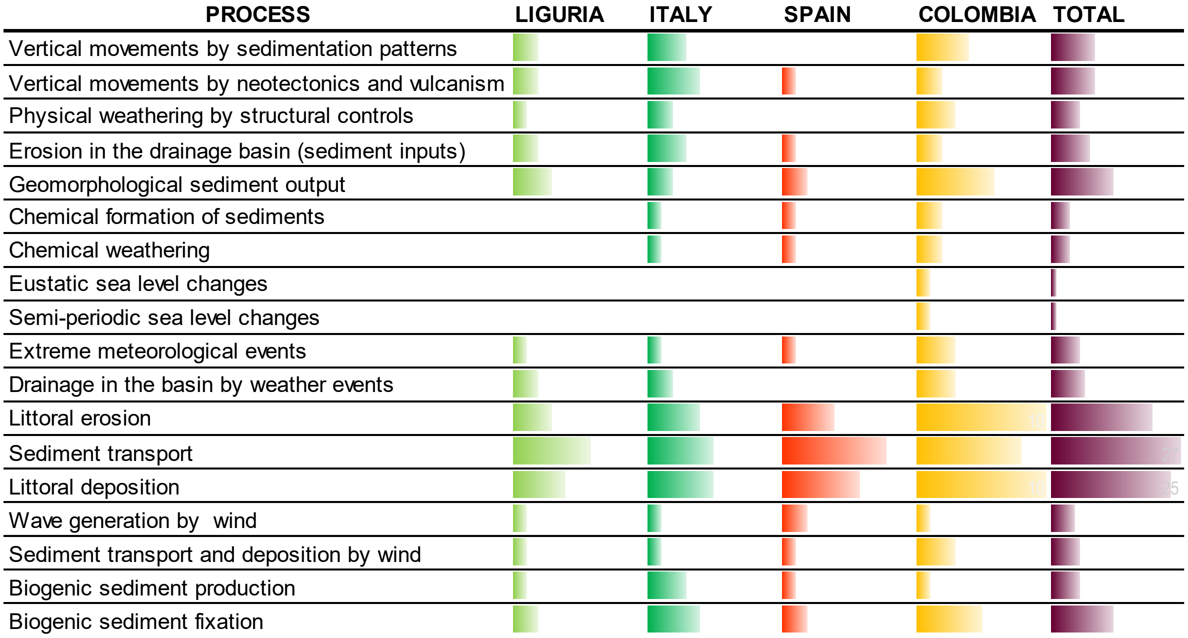


Figure 2.3. Frequency of technical requirements for the EIS preparation of coastal protection works by territory according to a scheme of natural processes influencing coastal morphology

Initially, three processes related to hydrodynamic controls (erosion, deposition and sediment transport) present the highest frequency of references within reviewed documents, mostly due to the bias of the guidelines. Documents selected for analysis focus on projects or activities linked to shore protection structures and marine works, therefore the studies lean on the stability of littoral sediments. The processes that follow in frequency are biogenic sediment fixation and the geomorphological sediment output; the latter is linked to sediment losses from the littoral balance such as submarine canyons or channels (Pranzini, 2008; Correa et al., 2005). Criteria sorted by these two processes also stress controlling mechanisms for the stability of littoral sediment, which is the utmost purpose of the interventions for which the analyzed EIS guidelines are formulated.

Processes related to physical/chemical courses (sediment formation and weathering) and global climatic phenomena (sea level changes) present the lowest frequencies. The pattern in the former group can be attributed to limited scientific and technical knowledge regarding transformation rates and measurement techniques in the coastal context (Rivas et al., 1997). This situation evidences a need to address applied research about the influence of natural processes on coastal dynamic for

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[1] Italian acronym of the Higher Institute for Environmental Protection and Research

EIA purposes. On the contrary, the low frequency of the latter group of criteria is owing to the local character of EIA, in which global phenomena are left in the background because they transcend the context of the influence area (Hapuarachchi, Hughey, & Rennie, 2016). This situation reflects an additional mistaken approach where the EIA dismisses global scale phenomena because the impact of projects lacks magnitude and intensity at this gross observation level. However, the relevance of global processes relies on the environment-project relationship, rather than project-environment, as a good precautionary EIA practice involves the management of risks to which the intervention would be naturally exposed (Cavallin et al., 1994; Joseph et al., 2015). Nevertheless, coverage of processes influencing coastal morphology is different in each territory, being Colombia the only one with the highest number in all criteria. Spain presents the lowest coverage missing 28% of the processes, followed by Liguria with 22% of its processes disregarded, while Italy only misses 2 (11%) within the technical criteria considered.

An additional element worth mentioning is the Italian document 'Guidelines for the Preparation of the Environmental Monitoring Project (PMA) for Works Subject to EIA Procedures' (ISPRA, 2015), in which references are systematically given to orientate the sampling of technical criteria for environmental monitoring at different project timings: before (characterization of the environment), during and after (operation). Most of the criteria proposed in this document are described according to the minimum lapse of observation, spatial coverage and suggested techniques. This is the only document of its kind within the guidelines found among the four countries analyzed; no other official document of ToR gives such a level of technical detail to orientate the environment characterization and monitoring.

2.5. Good practices for environmental licensing of coastal interventions

Good practices were extracted from the systematic analysis of similarities and differences among the four countries and further contrasted with acknowledged international good practices. As stated in the introduction, Morgan (2017) was the main reference for good EIA practices, complemented by Joseph et al. (2015), who reviewed existing literature on the best practices of environmental assessment, synthesized guidance from additional relevant literature in other fields and identified 74 good EIA practices. The following seven good practices are filtered from this catalog, according to the experiences of the four countries and how such experiences highlight the practices that favor the specificity of the coastal environment along the ELP.

2.5.1. The integration of screening and scoping stages within the ELP

According to Joseph et al. (2015), screening and scoping improve the quality of the EIS and latter stages of environmental assessment and decision making. As an example, Guerra et al. (2015)

reported the integration of the screening and scoping stages within 12 case studies of interventions in the marine environment of eight countries. Italy and Spain integrate the screening through the lists of projects subject to these pre-assessments because it is transposed by the EIA European Directives, whereas Colombia disregards this initial review at any level (Bassi et al., 2012; Fuentes-Bargues, 2014). Even if Cuba does not have a distinction of interventions subject to screening, this stage can be considered embedded in an advanced stage of the EIA procedure rather than a preliminary review. The requirement of an extended EIS from the environmental authority, when the area of interest has not been previously characterized by other projects or activities, is a way to impose a detailed review for potentially acceptable interventions in Cuba.

Still, effective screening requires thresholds and criteria, in addition to a list of activities, to determine if an intervention needs to be evaluated (Jay et al., 2007; Wood C., 2003). A good EIA practice relying on Earth Science can be inspired by the European model. Both Italy and Spain singularize coastal zones and wetlands into the specific areas that represent a sensitive location for intended projects; therefore, this may account for detailed scrutiny according to the EIA regulation. The amendment of the EIA Directive of 2014 has complemented this geographical approach with riparian areas, river mouth and marine environments (Lonsdale, Weston, S., Edwards, & Elliott, 2017). Such precisions insinuate the need for defining the susceptibility of such specific environments to the effect of human interventions, by considering the particularities of their physical-natural processes.

Additionally, Section 2.4.1 marked the public involvement as a good practice when setting criteria and relevant issues for the EIS elaboration, which comprehend the scoping stage. It has been proven that early consultations with the public improve the quality of EIS's because proponents can identify all potentially impacted receptors and collect information about the local environment (Barker and Wood, 1999; Lonsdale et al., 2017; Del Furia and Wallace-Jones, 2000). Furthermore, residents of coastal areas treasure empirical knowledge about the hydrodynamics and long-term processes modeling the zone where they have lived for decades, as highlighted by Correa and Gonzalez (2000). Therefore, local communities' observations could orientate the environment characterization and possible forecasting by highlighting the more pertinent elements for the impact assessment.

In consequence, Spain and Italy include a public information procedure to collect observations and complaints from the individuals affected before approving any environmental license and especially for defining the level of detail required in the assessment (Bassi et al., 2012; Enríquez-de-Salamanca et al., 2016). On the other hand, Cuba and Colombia do not prioritize public consultation in the scoping process because the former relies on the concept of public administrations, and the latter backs on terms of reference, which is the most explicit definition of scoping (Joseph et al., 2015).

2.5.2. Evaluation focused on the environment rather than the intervention

The analysis in Section 2.4.2 stresses that EIA procedures should be aligned by the type of environment affected (rather than the type of intervention to be developed), and this is partially reinforced in some of the regulatory frameworks studied. Among the four countries, Cuba is the only one that makes real distinctions about the kind of environment where an intervention is projected. In brief, Article 19 of Decree-Law 212/2000 establishes that projects and activities within the coastal and protection zones undergo compulsory environmental licensing. More specifically, within the list of interventions subject to environmental licensing in resolution 33/2015, three statements specified restrictions defined by the coastal environment rather than the characteristic of the intervention itself. As an example, permanent facilities in cays (a coastal environment) are always subject to environmental licensing, as well as any facilities located in their protection zone.

Allusions to the location in the regulatory framework of Italy and Colombia, related to natural protected areas rather than the kind of intervention, already exist. However, such precision does not detail the coastal zone context because it comprises natural parks in Colombia, be it marine or terrestrial, and indistinctive sites of interest for the European Community according to the Habitats Directive (92/43/EEC). On the other hand, within the criteria conceived for the screening procedure in Italy and Spain, specific attention is given to the carrying capacity of some marine and coastal environments, although there is no methodological reference for such estimation. (Loro, Arce, Ortega, & Martín, 2014) developed a method for estimating territorial carrying capacity in the context of EIA; however, it is not specific for coastal environments. In the main, it is worth highlighting that the emplacement of projects in coastal environments increases the magnitude of the environmental assessment regardless of the characteristics of the intervention within European procedures.

2.5.3. The inclusion of the coastal zone delimitation in the environmental licensing

An important activity in the generic impact assessment is related with the definition of the projects' influence area because this is the geographical limits of the measurements for characterizing the environment, estimating the effects of the intervention and implementing the environmental monitoring program (MAVDT, 2010). In consequence, consideration of coastal dynamic principles in the definition of the intervention's influence area could be considered a good practice based on Earth Sciences. Despite the lack of uniformity for setting coastal boundaries within countries (Milanes, 2018), the schemes of Cuba and Liguria can work as technical bases for defining the influence area of an intervention in the coastal zone. Both systems have a complementary effect since they address the cross-shore and longshore delimitations of coastal segments respectively. Colombia is the only country that specifies influence area delimitation in their ToR, requiring an iterative exercise for adjusting the final influence area from preliminary definitions segmented by the group of components (biotic, abiotic, socioeconomic). However, technical criteria specific to coastal environments are not detailed in the Colombian EIA guidelines.

Spain and Italy define the coastal zone from the boundaries of the maritime public domain, which correspond to the land portion shaped by marine action (Lami, Nebbia, & Villamena, 2010). Overall, both European countries make these boundaries known to the public, while the public domain delimitation and acknowledgment in Colombia are restricted to the National Maritime Authority (DIMAR by its acronym in Spanish). In Cuba, criteria for the limits of coastal and protection zones are set in Decree-Law 212/2000, according to coastal geomorphological features (dune, lagoon, swamp, cliff or river mouth) and hydrodynamic trends (riverine tidal influence and historic sea-flooding). In this sense, Cuba sets a technical reference for framing the reach of the impact of human interventions in the coastal zone. However, it is insufficient because the limits offshore are too wide for impact assessment purposes since they set it as the insular platform (usually 100 to 200 m. water depth). In this regard, the local experience of the Liguria Region represents both the technical complement of delimitation criteria and the example of practice in ELP. Liguria has sectorized its coast to support the environmental licensing of coastal protection works by setting three levels of longshore delimitation: physiographic units, intermediate units (paraggio) and littoral cells. When the EIS is elaborated or reviewed, the Coastal Marine Environment Protection Plan is a binding reference that defines all physiographic units, paraggio and littoral cells, which are also mapped and costless available online.

Finally, EIS preparation guidelines for coastal defense works and sand nourishment in Liguria and Colombia requires the framing of the intervention within similar analysis units, such as watersheds, littoral or coastal cells, environmental coastal units, ecosystems or territorial units. The advantage in the Liguria Region is the availability of a pre-defined coastal delimitation considered for EIA procedures, which can be configured as a relevant good practice in Earth Sciences. The Emilia-Romagna Region also has a pre-defined delimitation of littoral cells, established in a robust program for managing shore erosion; however, this information system is not binding in the EIA procedure (Montanari & Marasmi, 2014). All in all, the described practices of Liguria Region and Cuba poses good references on how technical criteria, scientifically proven, are introduced in the regulation that orient EIA procedure.

2.5.4. The institutional articulation in the ELP

The ability of organizations involved in the environmental licensing to achieve their interests and objectives largely determines the performance of the EIA (Kolhoff, Driessen, & Runhaar, 2018). Therefore, the articulation of the institutions involved in consulting procedures contributes to an integrated assessment and control of human perturbations in the environments. The fragmented approach conventionally used for characterizing the environment and assessing the impacts implies a competence distribution among several agencies and institutions involved in the components of soil, water, atmosphere, biota and society. If the environmental impact evaluation, monitoring and control are not coordinated by type of environments (i.e. coasts, highlands, continental water, submarine, fluvial), institutions in charge of each environmental component must be represented in the EIA procedure. Among the four countries analyzed, the institutional articulation has proven important in the stages of screening, scoping and follow-up.

Section 2.4.1 signalized that all the four countries conduct consultations with public administrations during the initial stages of the EIA procedure; the institutions considered in each country are listed in Appendix II-D. It is interesting to notice that only Cuba and Spain specify a list of institutions whose consultation is compulsory, according to their EIA legal code, being the former the longer of the two. The character of compulsory institutions in Cuba suggests that consultancies mainly verify technical viability and sufficiency of existing facilities to absorb the demand of a new activity in terms of supplies, human health, security and risk management. In Spain, half of the compulsory agencies are responsible for the management of hydraulic, terrestrial and maritime domains, which favors the coastal zone. Concerning Colombia, mandatory institutions to consult during EIA are not established, although this country has a pool of organizations that could be involved in such procedures within the National Environmental System (SINA by its acronym in Spanish). SINA comprehends five scientific institutions, one of them with special relevance to marine and coastal environments.

Institutional articulation may also optimize environmental licensing through the verification of the environmental compliance reports of licensed projects. This means that the assessment of management measures and its monitoring programs is distributed among the entities involved in the consultation procedures instead of only being reviewed by the environmental authority. This is the case of the cooperative surveillance in the Cuban system. It also happens in the Italian system, where the project executor presents the evidence of environmental prescription directly to the institutions assigned in the license for the verification. This mechanism ensures that the most suitable technical staff review the outcomes of the parameters assessed, because every institution masters their specialties (biodiversity conservation, maritime domain, water supply, sanitary pollution, geological hazards). At the same time this implies a challenge in terms of integration of an environmental compliance judgment, because the concepts are spread among the entities consulted; therefore, a higher level of coordination and awareness of institutional competences is required. As a second positive side, this practice overcomes the limitations that technical staffs of environmental authorities usually have when facing the follow-up of interventions in a variety of environments.

2.5.5. Accreditation of environmental consultancies for conducting EIS

Consultants have a key role in good EIA practices as they hold the most practical knowledge, and because they also face the challenge of maintaining good relationships with their clients and at the same time a good professional reputation (Kågström, 2016). Therefore, accredited impact assessment staff is a legal and procedural incentive, considered to be a good practice because it ensures accurate and high-quality assessment without bias (Joseph et al., 2015). Within the four countries analyzed, Cuba is the only one where consultants in charge of EIS elaboration are periodically certified by the Ministry of Science, Technology and Environment (Chapter VII of Resolution 132/2009). This is a meritocratic certification, rather than merely procedural, since it is supported by scientific requirements and selective experience.

During the accrediting application in Cuba, consultancies need to submit a list of projects or activities, for which the entity is considered competent, and demonstrate experience in the field of environmental sciences. Evidence of such requirements is post-graduate courses taught and/or scientific publications made by the consultant team. Another requirement relevant to this argument is the demonstration of technical potential for EIS elaboration through the list of duly qualified specialists employed for carrying out these studies. In this regard, Italy and Spain limit the EIS assessment and review to competent experts, which should force authorities to have sufficient expertise in projects and environments under licensing (Lonsdale et al., 2017). In the main, EIA analysis in Italy, Spain and Colombia focus on the limitations and challenges of environmental authorities for controlling EIS quality, while Cuba addresses the issue by certifying consultancies with standards of scientific-technical support and selective experience.

Therefore, ensuring the aptitude of experts preparing the EIS of coastal interventions through a certification could be considered a good practice in which Earth Sciences are relevant. Moreover, such aptitude needs to rely on the scientific and practical experience of the consultancy in the particularities of the coastal environment and its natural processes. In this regard, the Cuban experience encourages a solid articulation of cutting-edge scientific knowledge with the ELP.

2.5.6. Pertinent official guidelines for sensitive EIA stages according to types of environments

The most sensitive EIA stage requiring orientation is the EIS elaboration. Guidelines in this stage are important because they set the pillars for characterizing a perturbed environment and defining the coverage of the impacts. Additionally, guidelines allow the impact valuation to be normalized with other interventions in the area through a validated assessment methodology; but they also participate in the design of the management plan through the definition of follow-up parameters. Thus, the availability of comprehensive guidelines for applying impact assessment methods has been considered a good EIA practice in other studies (Joseph et al., 2015). Among the countries analyzed, Cuba is the only one without guidelines, having only the indications about the EIS content in Chapter III of Resolution 132/2009. However, in all four countries, this legal indication concerns the structure of the document rather than details about characterizing the environment, methodologies for defining the influence area and evaluating impacts, or parameters for monitoring (Toro et al., 2010; Bell et al., 2017). Regarding the structure of the EIS content, some differences among countries have been found. For instance, the Spanish framework is still missing the element of risk management, whereas the amended EIA directive (2014/52/EU) and the other three countries include the risk to accidents, disasters and climate change in the assessment and decision making.

Colombia stands out in terms of quantity of guidelines because up to 2017 the ministry of environment has published three manuals for the institutional EIA procedure (MMA and SECAB, 2002a; MMA and SECAB, 2002b; MAVDT, 2010) and another 40 ToR for environmental studies of projects and activities. Although the guidelines analyzed in Section 2.4.3 were downloaded from the website of the ministries of environment of Colombia, Italy, Spain and the Liguria Region, it was not verified precisely how extensive is the list of guidelines in Spain and Italy because these documents are not gathered in a single repository, as the national environmental licensing authority of Colombia do (ANLA, 2017). Despite of this, Section 2.4.3 already revealed that EIS guidelines in Colombia are exhaustive because they include a very extensive list of information requirements. However, such exhaustiveness may lead to redundancies due to the conventional segmentation of criteria by components rather than processes. Therefore, this cannot be considered entirely as a good EIA practice for coastal interventions because management principles stress that it is better to be more pertinent than exhaustive (Vallega, 1999).

Another sensitive stage in the environmental licensing linked to official guidelines relates to the follow-up, despite being conceived during the EIS preparation. Drafting monitoring programs to verify the environmental compliance is a constant recommendation for ELP, which should be legitimated in legislation and guidelines to scope the follow-up (Bassi et al., 2012; Elliott, 2011). In this regard, Italy is the only country that fulfills this good practice because it establishes standard survey, monitoring methods and interpretation references, as suggested by Lonsdale et al. (2017). While Liguria has criteria for monitoring shore protection works and periodical beach nourishment at the regional level, the guideline of (ISPRA, 2015) applies for any kind of intervention because it is structured by environmental components or ambits. The structure of this last national guideline defines specific methodological indications for six ambits and a list of parameters that can be used in the monitoring program according to the purpose of the follow-up stage. In summary, these criteria are the closest experience resembling the good practice of focusing EIA guidelines on the kind of environment rather than the type of intervention.

2.5.7. The integration of environmental geographic information

Another good EIA practice, normally associated with the follow-up stage, is recording the outputs of monitoring activities for future environmental assessment and implementing data management platforms for this purpose (Joseph et al., 2015; Bassi et al., 2012). EIA practitioners in the four countries analyzed use information services for characterizing the environment during the EIS preparation and, possibly, as data supply for the monitoring program. Still, authentic good practices in Earth Sciences resemble the data model enforced in Colombia for presenting the geographical information of projects along the ELP.

Of the four countries, Colombia has the most advanced environmental information system through the National Geographic Environmental Data Storage Model, created and updated by the National Agency of Environmental Licensing (ANLA) since 2012 (Resolution 1415/2012; Resolution 0188/2013; Resolution 2182/2016). Such integration of the information has allowed the implementation of a strategy for estimating the synergic effect of interventions with overlapping influence areas, called Regionalization (Solarte, 2017). Geographic products and services derived from this strategy are still restricted to the internal staff of the environmental authorities, aiming to support decision making and optimizing EIA procedures. Despite these advantages, the data storage model is not sufficient for coastal environments because the attributes established in the structure do not address current information gaps in the marine-coastal context. For example, less than 10% of the feature class in the data structure is gathered in two data sets under the names of Biotic-Continental-Coastal and Marine. This reflects Colombia's ongoing need for a better understanding of coastal processes in EIA procedures for pinpointing the complex dynamic of the land-sea interphase.

In the cases of Spain, Italy and Cuba, the integration of environmental information for EIA purposes exhibits only initial levels of implementation. At European level, the Inspire Directive (2007/2/EC) aims to create a European Union spatial data infrastructure for the purposes of EU environmental policies. However, the interviews in Italy and Spain reported no protocol of spatial data validation or integration within this directive, which indicates that its institutionalization has not penetrated effectively into the local environmental management level. In Spain, EIA representatives mentioned the existence of a geographic information system where many layers are compiled, however, only environmental authorities can consult it and the specificity in marine and coastal issues is cataloged as poor. In Italy, the 21 regional environmental protection agencies (ARPA/APPA) and ISPRA are configuring a network to integrate the monitoring and control of environmental quality within the Italian territory. This National System for Environmental Protection (SNPA by its acronym in Italian) was created as an attempt to recover the control and homogeneity of what is done in every region. Finally, EIA practitioners in Cuba can only consult isolated information that has not been synthesized due to an incomplete database. However, the office of the Ministry of Environment in the Matanzas Region is testing a computerized system, called SARGAE, designed to systematize the environmental information and obligations of projects in situ. The program would generate a report with the environmental diagnostic, which in the future will be linked to the information system of the competent environmental authority.

2.6. Conclusions

Four countries have been compared for the first time according to EIA best practices and their application in their respective environmental licensing on the coastal zone. As an innovative approach, the comparison included ToR and guidelines, apart from the EIA legal code of each country, because studies so far have only concentrated on EIS and legal approaches. The main findings regard the identification of strengths and shortcomings of Italian, Cuban, Spanish and Colombian ELP. According to critical interventions and pertinent criteria for characterizing processes influencing the coastal morphology, a set of seven good practices were conceptualized.

The study enhances the importance of technical criteria in defining coastal boundaries to scope environmental impacts and gauge the effect of interventions on natural processes. These suggest a changing approach in the way impact assessment is performed, by shifting from a fragmented-oriented analysis with environmental components to a process-oriented analysis of natural flows within a kind of environment and its neighboring connections. In this sense, geomorphological processes play a core role in identifying, assessing and monitoring the influence of human interventions on coastal environments.

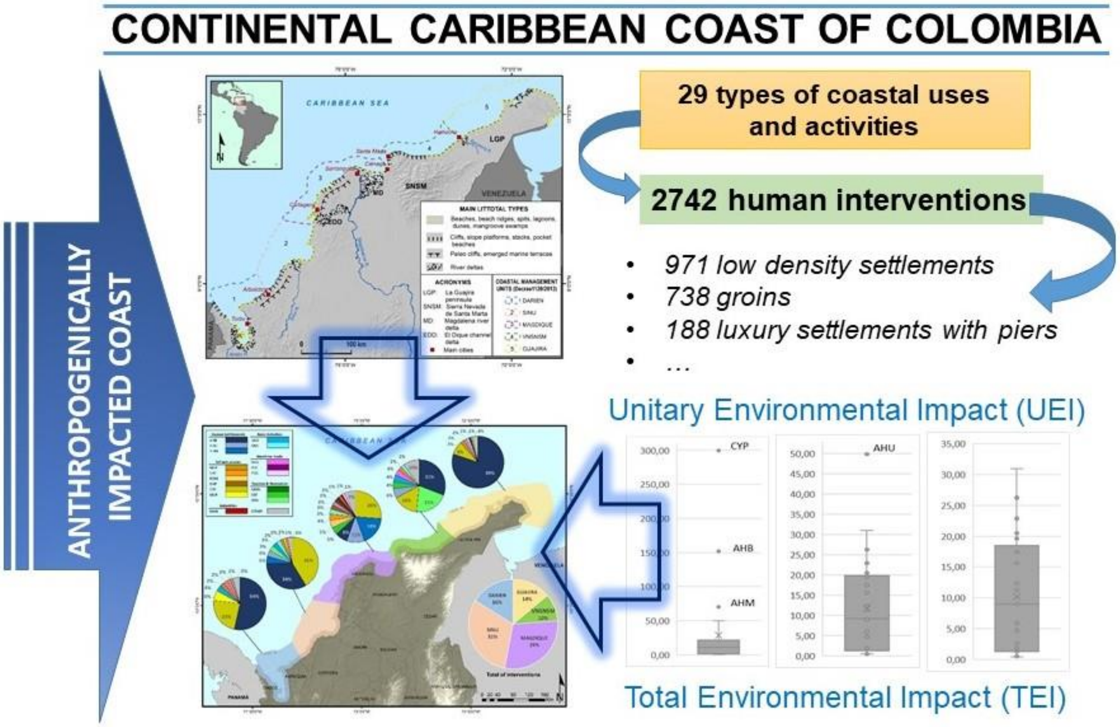
Improvements that might be redressed by implementing the suggested good EIA practices include the provision of official methodological guidelines for EIS elaboration, articulation of EIA information systems and accreditation of environmental consultants to homogenize good practices in Earth sciences for the Italian procedure. In Cuba, the provision of official methodological guidelines for EIS, articulation of information systems for EIA procedures and the proactive participation of the public within the scoping and screening stages are suggested. On the other hand, Spain could improve the availability of official methodological guidelines for EIS elaboration, articulation of information systems for EIA procedures, criteria definition for influence area and accreditation of environmental consultants. Lastly, Colombia needs to improve the ELP by integrating a screening stage, binding the coastal delimitation for scoping the influence area of interventions, accrediting environmental consultants and articulating institutions during the follow-up.

In consequence, a new perspective with respect to the conventional environmental licensing scheme is suggested. Procedures and guidelines must be oriented by types of environments rather than types of interventions because the characteristics of impacts are better correlated to natural processes than to project design. In the end, these designs are adaptable, while natural processes are inherent to the kind of environment. In addition, geomorphological processes present engineering challenges to the human interventions, in terms of risk management, and frame the character of the environmental impact.

All in all, the seven good practices defined in this study are recommended as principles to homologate the environmental licensing of interventions with influence in the coastal zone. Further research should be done around the definition of coastal susceptibility to the effect of human interventions and its articulation with territorial planning instruments; it will greatly optimize the environmental assessment, monitoring and control of projects, built structures and activities. Moreover, methodological approaches for estimating territorial carrying capacity of human intervention in the coastal zone shall be investigated, with the goal of complementing the assessment stage during ELP.

CHAPTER III

Anthropogenically impacted coast: An evaluation of human interventions in the Caribbean Coast of Colombia



CONTINENTAL CARIBBEAN COAST OF COLOMBIA

29 types of coastal uses and activities

2742 human interventions

- *971 low density settlements*
- *738 groins*
- *188 luxury settlements with piers*
- *…*

Original versión of the manuscript submitted on 04-Sept-2018 to the research journal Anthopocene

3.1. Abstract

Many coastal areas have been influenced by human interventions; however, the environmental impacts of their interventions are rarely assessed. To identify the dominant coastal interventions in Colombia, a baseline was established along its continental Caribbean coast based on 29 types of human interventions cataloged via Google Earth images. In total, 2742 human interventions were located, the most common being low-density-settlements (n = 971), groins (n = 738), and luxury settlements with piers (n=188). In addition, the environmental impact of each type of intervention was assessed, based on the extent, intensity, reversibility, and persistence of their effect on coastal processes, as well as their frequency. The three most impactful human intervention types were equivalent to those with the highest frequency; however, some interventions (e.g., high density settlements or road infrastructure) had higher environmental impact values than other more frequent (e.g., luxury settlements or aquaculture). In addition, the highest values of environmental impact correspond to material extractions and infrastructure assets such as breakwaters and seawalls; however, none of these were within the ten most impactful interventions identified on the study area.

3.2. Introduction

Despite being one of the most biodiverse countries in the world, a fact which is made intricate given its cultural multiplicity (DANE, 2012a), Colombia exhibits a conventional system for Environmental Impact Assessment (EIA), with equal or even lower robustness than countries with lower natural and cultural richness (Pereira, Botero, Correa, & Pranzini, 2018; Toro et al., 2010). Regarding coastal environments, the impacts of human interventions on natural and cultural riches have been a concern for decades. For example, in the 1970s, Great Britain’s Heritage Coasts Project assessed the negative effects of recreation facilities, housing, mechanized agriculture, groins, and other interventions impacting their coasts (Williams and Howden, 1979).

In general terms, EIA is a process for identifying, predicting, evaluating, and designing mitigation measures for any relevant effects of development proposals prior to making a major project decision, particularly regarding biophysical and social aspects (IAIA & IEA, 1999). Despite this assessment’s worldwide acceptance as an instrument for environmental management, several omissions overshadow its effectiveness. When assessing the potential impacts of a new individual intervention over an anthropogenic area, the cumulative and synergic effects that existing human developments may introduce to the analysis are often overlooked (Folkeson, Antonson, & Helldin, 2013). Hence, the environment’s capability of absorbing the combined effect of such perturbations, without losing substantial environmental values, is an effective concept in EIA context (Loro et al., 2014; Santoso, Erli, Aulia, & Ghozali, 2014). Naturally, this approach requires a baseline of such existing human perturbation, which comes along with an inventory of all works and activities affecting the area of developmental interest.

In coastal areas, partial inventories of human interventions have been conducted in several countries for various purposes. Barragán and de Andrés (2015) analyzed coastal cities and agglomerations of interest to integrated coastal management, and accounted for densely populated human settlements around the world via city population databases and Google Earth imagery. At a regional scale, Dias et al. (2013) canvased over 60 sites along the coasts of Brazil, Argentina, Spain, and Portugal to analyze the anthropogenic impacts on Iberian and American coastal areas. According to the historical alteration of coastal sites, the authors devised the categorization of six levels of anthropogenic impact related to well-defined activities, such as tourism and salt ponds. At a local level, Ali and El-Magd (2016) identified landform transformations caused by human activities (e.g., urban development and fish farming) to reconstruct the geomorphological evolution of the Nile delta's coast through the spatial analysis of satellite images, spanning 25 years. Most specifically, Pranzini et al. (2015) inventoried the coastal defense works in 25 European countries, to analyze shore-protection strategies on the continent. Similarly, Bezzi et al. (2018) identified hard and soft interventions within the monitoring platform of littoral cells, to assess the effectiveness of shoreline erosion management in the Veneto Region (northeastern Italy).

In Colombia, the only type of human intervention properly inventoried corresponds to shore-protection structures, and it has been recorded at different geographical levels by government institutions and academics (Correa & Vernette, 2004; Posada et al., 2009; Rangel-Buitrago et al., 2012; Rangel-Buitrago, Williams, et al., 2018). Although the national environmental authority has developed a database model for environmental licensing (Solarte, 2017), the information it contains is restricted to the projects and activities under its national competency; thus, the interventions regulated at regional and local levels are not included. Consequently, no inventory of all the interventions affecting the coastal zone has ever existed in Colombia. Therefore, this study seeks to identify all the human works and activities in the Continental Caribbean Coast of Colombia (CCCC), to generate a baseline of the environmental impact currently affecting this coastal area.

3.2.1. Study area: The CCC

The CCCC is located at the northwestern corner of South America, a region deeply influenced by the subduction of the Nazca and Caribbean plates under the South American plate (Correa & Morton, 2010). It has been shaped by the formation of thick-tertiary accretionary prisms with huge quantities of sediment supplied by the erosion of the northern Andes (Duque-Caro, 1984). In general, the Caribbean coast is a mosaic of differentiated tectonic blocks (within low to medium seismic risks) affected by numerous NE-NW and E-W active fault systems (Correa & Morton, 2010; Correa &

Pereira, 2019). Interactions between natural geological processes and historical anthropogenic activities in coastal watersheds have resulted in extremely unstable coastal geomorphology with environmental deterioration in several places (Correa & Pereira, 2019). Coastal erosional and accretionary events measured in tens of square km take place at coastline change rates up to 40 m/year (Correa, 1990; Correa et al., 2005; Correa and Paniagua, 2016).

The extent of the shoreline in the study area approximates 1,700 km, along which tectonic activity has configured a combination of mountainous areas with deltaic plains from the three major Colombian rivers (Magdalena, Sinú, and Atrato) (Correa & Pereira, 2019; J. Restrepo & López, 2008). Figure 2.1 presents the main characteristics of the coastal morphology of the study area, where deltaic plains are shown as beach-lagoon systems, spits, and sandy barrier islands linked to extensive mangrove swamps. These low-lying coastal features alternate with cliffs and rocky shores in the areas of medium-high mountains, constituted by igneous and metamorphic rocks around the Sierra Nevada de Santa Marta (SNSM) massif and the border with Panamá, and various sedimentary rocks in La Guajira peninsula (DIMAR-CIOH, 2013). In the southern coast, between the deltas of the Magdalena and Atrato rivers, the rocky shores are linked with sedimentary depositional and erosional marine terraces, which emerged during late Holocene times (Correa & Morton, 2010).

This same southern Caribbean coast is influenced by the mud diapiric phenomenon, a reformative process of marine floors and onshore areas due to buried low density materials intruding on the surface. Mud diapirism has profound effects on the coastal geomorphology of the area acting as the main control of the depositional patterns in the area, and as a driving process for the formation of extensive shoals and coralline archipelagos, such as the El Rosario and San Bernardo islands to the south of Cartagena city (Carvajal et al., 2010; Vernette, 1989). As physical littoral occupation and human development spread along the southern Caribbean coast, violent diapiric extrusions and associated effects, such as fires, surface fracturing, and differential vertical movements, are transforming into a first-order geological hazard in the area. This situation has been exemplified by the violent eruption of the mud volcano, El Cacagual, near the city of Turbo, that caused nine fatalities on December 19, 1992 (Mendivelso, Carvajal, & Pinzón, 2010).

From a socioeconomic framework, the CCCC exhibits higher levels of economic development compared to the coastal zones facing the Pacific Ocean; although, the five most populated cities in the study area (Barranquilla, Cartagena, Santa Marta, Ciénaga, and Riohacha) concentrate only 6.4% of the total national population (DANE, 2012a). The commercial and port activity is mostly focused in the cities of Barranquilla and Cartagena, while the greater tourist activity in the country, within the 3S tourism category, is gathered in Santa Marta, Cartagena, and Coveñas (DANE, 2012b; MINCIT, 2011). Additionally, the primary economy sector (agriculture, livestock, and mining) represents the main activity in five of the eight coastal departments of the study area (Choco, Cordoba, Sucre, Magdalena, Guajira), with very low participation from fisheries (DANE, 2012b).

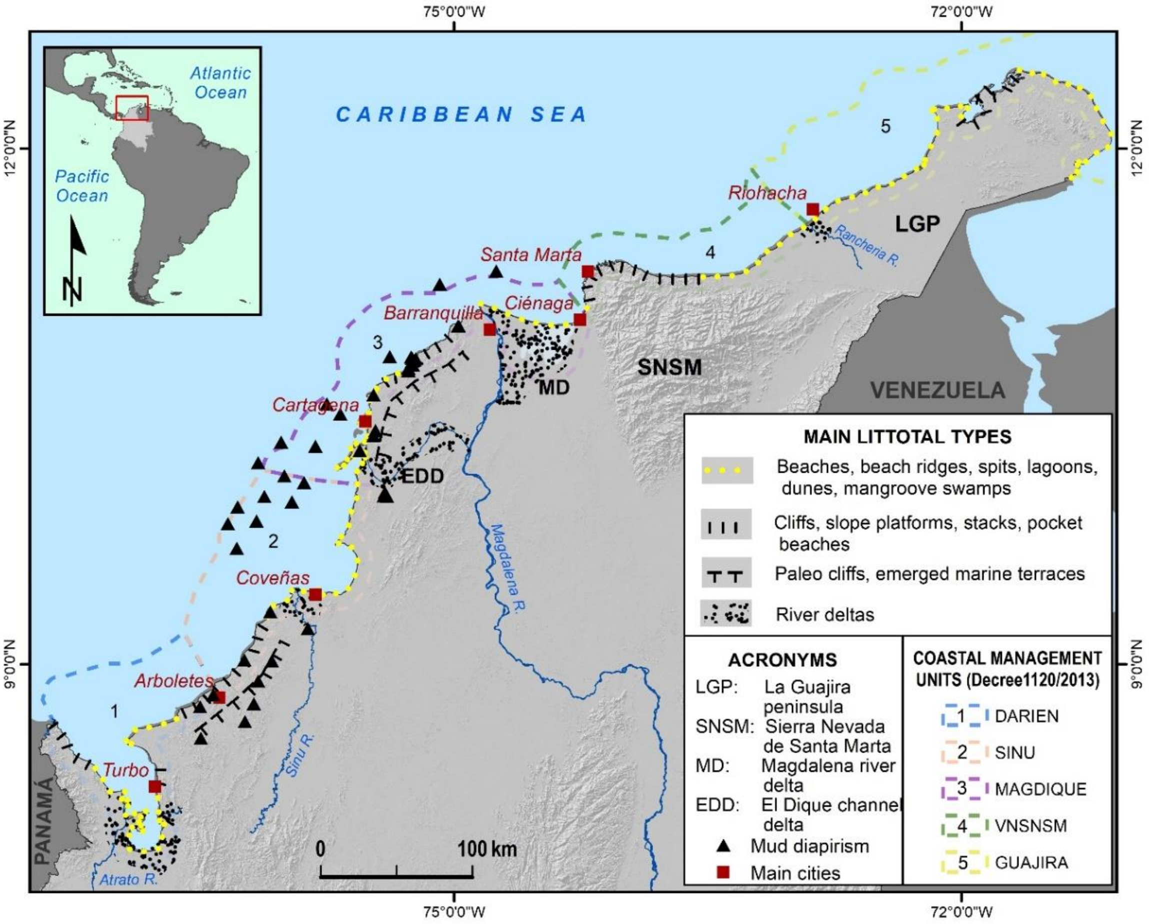


Figure 3.1. Study Area: CCCC. Adapted from Correa and Pereira (2019), Carvajal et al., (2010), and Vernette (1989).The acronym MAGDIQUE refers to the unit Magdalena-Canal del Dique and VSNSM to the unit of the northern slope of Sierra Nevada de Santa Marta

From a geographical perspective, the CCCC is divided into five environmental management units, each containing distinctive ecosystems with a similar structural connectivity and functionality, according to Decree 1120 of 2013. A representation of these boundaries is depicted in Figure 3.1 with dotted lines and a distinctive color for each unit: DARIEN, SINU, MAGDALENA, VNSNSM, and GUAJIRA. Therefore, the study area henceforth is also divided by the limits of each Environmental Coastal Unit (ECU), with the inland limits set at 2 km from the shoreline (Decree 1120 of 2013, Article 3, numeral 1c) and the same distance offshore.

3.3. Methods

The analysis of the environmental impact of human intervention on the study area comprises two general stages: 1. Inventory of the coastal interventions through the observation of open source satellite imagery. 2. Valuation of the environmental impact of the inventoried interventions through the assessment of the unitary importance of the impact and the frequency of accounts for every typology.

3.3.1. Inventory

To approximate the number of human intervention in the CCCC, an exhaustive list of intervention typologies was compiled using the structure of coastal uses and activities proposed by Botero et al. (2014). This scheme served as a reference to select more than 50 types of human interventions, in terms of land transformation, infrastructure, and joint facilities, whose emplacement within the terrestrial or marine limits of the coastal zone can disturb the natural processes influencing coastal morphology (Pereira et al., 2018). A code system was defined to represent the type of intervention using its first three letters, the ECU where it is located with the following three letters (see codes in Appendix III-A), and three digits for the numerical order, by unit and typology, e.g., the resulting code format, for the case of a type of human settlement in the SINU unit and the first item is AHU-SIN-001. Additional features to the code system were registered to represent the geometric character of the interventions inventoried. Interventions comprising an area were marked by four points with the same code and consecutive number, but with the letters N, S, E, and W to represent its Cardinal limits (e.g., AHU-SIN-021N; AHU-SIN-021S; AHU-SIN-021E; AHU-SIN-021W). Linear interventions, such as railways, roads, and even some human settlements, entailed two pints with the same code and consecutive number, but with the addition of a complementary binary digit to represent the beginning and end of the intervention (e.g., AHU-SIN-024-1; AHU-SIN-024-2).

The instrumentation for data collection relied on the software Google Earth because it provides easy access to numerous satellite images of the study area with high enough quality to observe the earth relief and identify geomorphological units, both natural and anthropogenic (Berry, Fahey, & Meyers, 2014; Harris, Nel, Holness, Sink, & Schoeman, 2014; Hossain, Bujang, Zakaria, & Hashim, 2016; Magaña, López-Ruiz, Lira, Ortega-Sánchez, & Losada, 2014). The image information was mostly sourced from the collection of satellite images from Google Earth but alternative imagery services were also used (©Nokia, ©Bing, ©ESRI). The majority of the georeferencing work registering the interventions was done through Google Earth; although, other geographic information systems, such as ArcMap from ESRI or the open source gvSIG, were used to assist the registration of the interventions within the alternative imagery inputs.

Among the tools of Google Earth, position marks and its editing options, historical imagery and street view were used. Almost 4,000 position marks were placed over Google Earth imagery to represent punctual, linear, and surface shape interventions within the 29 identified typologies. The tool for drawing polygons was also used to set the boundaries of five ECU, as a reference for changing colors in the marking points and to restart the numeration of the codes written in their labels (see the kml files on the digital Appendix III-B). Historical imagery proved as an efficient tool to recognize and differentiate the types of interventions by comparing images from different times and satellites within a single location. Ultimately, street view was used as a discriminating tool in areas with roads and streets. It provided 360° view through pictures on the ground that gave further details of the height and material of built structures around streets and roads. These details helped in differentiating one type of intervention from another.

Although the image resolution of Google Earth was mostly appropriate for the observation scale, high degrees of cloudiness on a few sectors of the GUAJIRA, SINU, and DARIEN units made it difficult to identify the interventions. In these cases, the alternative imagery services were used to mark the interventions obscured by clouds, and their geographic reference were then marked in Google Earth to keep all data in a single repository. In particular case of the DARIEN unit, the high resolution images of the spatial geodatabase developed by Prüssmann and Correa (2012), comprising the littoral geomorphology of the Urabá Gulf, was also used. A complementary table recorded the satellite and date of the image used for the identification of each intervention, together with its respective code and additional observations for further analysis.

3.3.2. Environmental Impact Estimation

To create relevant statements about the overall impact in complex systems, such as coastal zones, a mathematical equation for calculating the importance of the impacts proposed by Conesa (2006) was adapted in Eq. (1) and (2). The simplified expression of Eq. (1) calculates the importance of the impact of every type of coastal intervention, where UEI stands for the Unitary Environmental Impact (UEI), which is influenced by four attributes: extension (EXT), intensity (INT), reversibility (REV), and persistence (PER). According to the scores defined by the methodology of Conesa (2006), the assigned values for the assessment in the first two attributes may range from 1 to 12, while the others may range from 1 to 4. Finally, α refers to the maximum value possible from the total sum of the attributes.

$$UEI = (EXT + INT + REV + PER) / \alpha \quad \textbf{Eq. (1)}$$

A conceptualization of coastal processes (Bird, 2008; Masselink et al., 2011; Morton & Pieper, 1977; Pranzini, 2004; Prothero & Schwab, 2013), was used as a reference to differentiate the scale and/or dimension of the attributes in the assessment of each typology, particularly for EXT and INT attributes.

Such conceptual framework is consistent with a novel approach of impact assessments, in which the analysis of natural flows within a given kind of environment is closer to the character of the impact than the conventional analysis of segmented components (Pereira et al., 2018). Moreover, the overall environmental impact on the area also needs to consider the amount of occurrences of each intervention typology. Therefore, Eq. (2) introduced the frequency (Frq) as a multiplier of the UEI to calculate the Total Environmental Impact (TEI) by type of coastal intervention identified.

$$TEI = Frq\,(EXT + INT + REV + PER) / \alpha \quad \textbf{Eq. (2)}$$

According to the incompatibility principle, the simple aggregation operators of Eq. (1) and (2) favor significance rather than precision, in the overall impact assessment of the multiple types of coastal interventions (Toro et al., 2012; Zadeh, 1973). Such overall assessment was complemented by the application of descriptive statistics to the calculated values of TEI for each ECU and the entire study area. Graphical representation of data distribution, quartiles, and interquartile rages were used to refine data and highlight analysis on concentration and magnitudes of the environmental impact due to coastal interventions.

3.4. Results and discussion

3.4.1. Coastal interventions in the CCCC

Twenty-nine interventions were identified in the study area, among over 50 types of works and activities, which affect the coastal zone considered in this inventory (Botero et al., 2014; Pereira et al., 2018). The geographic distribution of coastal interventions in the CCCC is presented in Figure 3.2, wherein a pie chart shows their relative frequencies for each ECU. As a first evaluation, the gross-level pie chart reveals that 60% of the interventions identified were concentrated in the SINU and MAGDIQUE units, which relates to coastal length and morphology because the probability of having human interventions in longer and sandy coasts is higher than that in mountainous and rocky littorals.

A broad observation of Figure 3.2 stresses that AHB and CYP are the only two typologies represented with major percentages in all coastal units. AHB is the most representative typology in all the study area because it equates the extent of the human population in the territories in a spread out manner. Although human settlements fail to represent a classic subject of environmental licensing, they encompass joint facilities and land transformations, which contribute to a territorial approximation of the environmental state. Typology CYP, referring to a shore-protection structure conventionally termed “groins”, is the most popular infrastructure type determined along the extent of the CCCC, with representative percentages of appearances among all interventions in each ECU. This particular kind of rigid structure has been responsible for the instability of several kilometers of coast in the

Colombian Caribbean littoral as a co-lateral effect of localized interventions to counteract erosive tendencies (Correa et al., 2005; Rangel-Buitrago et al., 2015).

There are other nine typologies that were identified in all five ECU which could not be fully represented in Figure 3.2, since they comprised <1%, of the respective unit. Therefore, the label 'other' often grouped several of these categories, including infrastructure (MUP, CAP, and MUR), basic activities (UAG and GRA), industries (MAN), maritime trade (NAV and PUG) and tourism and recreation (EDN). Despite their reduced and heterogeneous representation among all ECU, these intervention typologies are relevant in terms of impact assessment because they are span across the area with the potential of increasing occurrences.

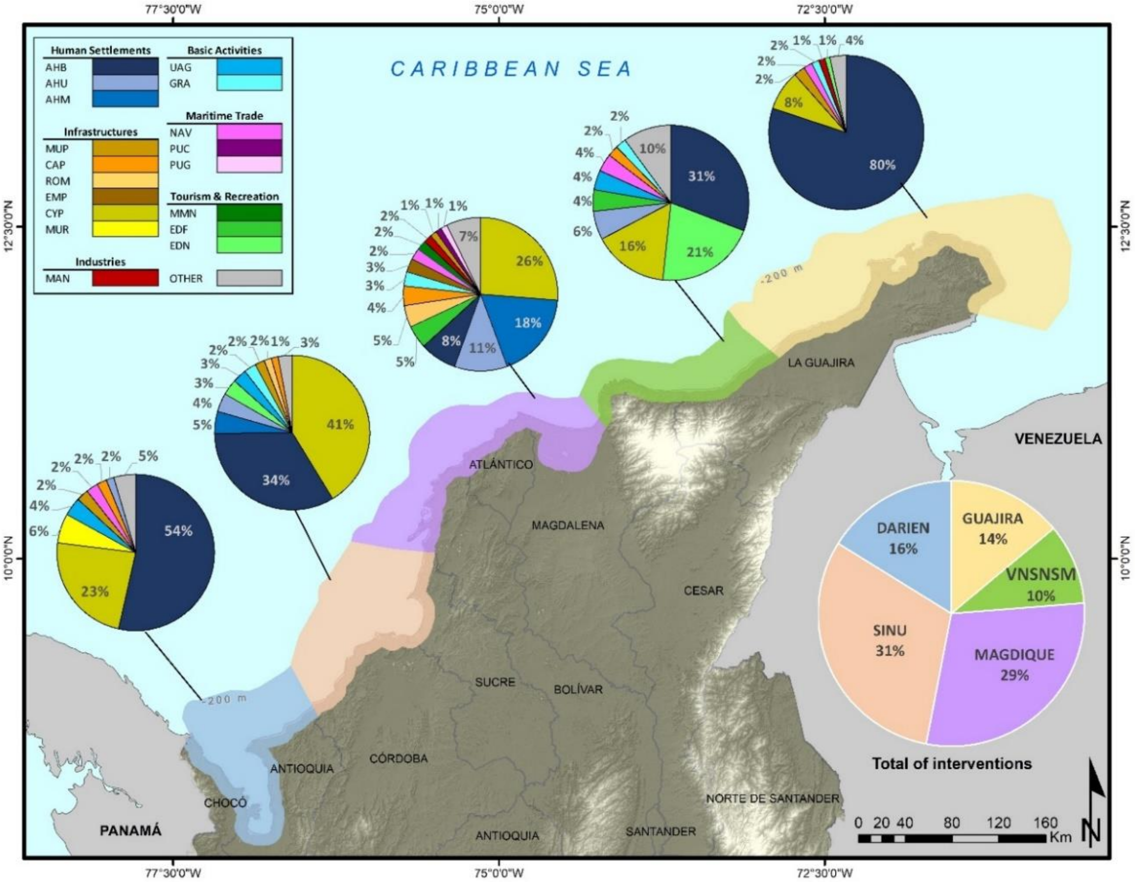


Figure 3.2. Intervention's distribution according to Environmental Coastal Units in the Colombian continental Caribbean.

Regarding geographical representation, the MAGDIQUE unit has the highest diversity of intervention typology from the 29 identified interventions (93%), followed by SINU (72%), VNSNSM (79%), DARIEN (55%) and finally GUAJIRA (41%). Despite exhibiting a medium-high typology diversity, VNSNSM contains the lowest total amount of interventions identified among all ECU, probably attributed to the orographic relief of the SNSM, which reduces the extent of coastal plains to being the shortest in the study (Correa & Morton, 2010). Conversely, the distribution of interventions in this unit comprises three gross typologies covering 68% of the interventions, the majority of which belong to low-density-settlements and a typology of tourism and recreation. Another 22% is almost evenly distributed among luxury settlements, sun and beach tourism, basic activities, maritime transport, and road infrastructure. The remaining 10% is distributed into 14 types within the categories of human settlements, infrastructure on shore, railway infrastructure, industrial typologies, maritime trade facilities, and tourism and recreation.

The distribution of interventions in MAGDIQUE has an even longer list of typologies, the majority of them (55%) relies on a kind of shore-protection infrastructure and on luxury settlements, with and without piers. Another 37% is distributed among the categories of human settlements, tourism and recreation, infrastructure, maritime trade, industry, and basic activities. The remaining 7% gathers the other 12 typologies in the categories of human settlements, infrastructure on the shore, mining, basic activity, industry, and, particularly, tourism and recreation. 75% of the interventions identified in SINU are distributed among types of human settlement and shore-protection infrastructure. Another 22% is distributed among two basic activities, two types of human settlements, a tourism typology, and other three types of infrastructure. The remaining 3% is spread in 11 typologies of the following categories: infrastructure, human settlements, the remaining basic activity, industries, maritime trade, and, particularly, tourism and recreation.

DARIEN has 77% of its interventions distributed into the two predominant typologies of most units, with a relation close to 2:1, on the intervention's account for the unit. Another 18% is distributed among a basic activity, three kinds of infrastructures, a maritime trade activity, and a type of human settlement. The remaining 5% is distributed among eight typologies within human settlement, a basic activity, an industry facility, a maritime trade facility, and two tourism intervention typologies. Finally, intervention diversity in GUAJIRA is restricted to 20%, half of which deals with infrastructure that is perpendicularly attached to the shore (e.g., groins, navigation channels). Another 6% is distributed among a human settlement and facilities for the activities of maritime trade, industry and tourism. The remaining 4% of the label "other" deals with five types of interventions in the categories of infrastructure, basic activities, and maritime trade.

Regarding the concentration of interventions, Table 3.1 summarizes the 14 typologies whose appearance in a single unit is more than 50% of the total count, within all ECU. These values complement the data represented in Figure 3.2, where MAGDIQUE appears as the most diverse unit because it also holds the highest concentration of interventions by typology, comprising 79% of the interventions on Table 3.1. In contrast, GUAJIRA unit registers the fewest amounts of interventions, either within the highly concentrated typologies (3.4%) or by the total of intervention typology represented among the 29 identified in the study (41%). It should be noted that the northern half of the GUAJIRA unit is a desert region (DIMAR-CIOH, 2013).

AHB represent an interesting typology because it is not highly concentrated in any particular ECU, and still represents over 80% and 53% of the interventions counted in GUAJIRA and DARIEN, respectively. Conversely, SINU concentrates almost half of all groins identified in all five units (CYP: 47%), making it one of the few interventions whose highest concentration is not in MAGDIQUE. Another exceptional case is presented in the MAGDIQUE unit, where the Barú peninsula figures as a hotspot for coastal interventions, particularly luxury settlements (AHM and AHU) that operate as second residences, due to the landscape value of the tourist beaches in the area (Rangel-Buitrago, Correa, Anfuso, Ergin, & Williams, 2013; A. T. Williams, Rangel-Buitrago, Anfuso, Cervantes, & Botero, 2016).

Table 3.1. Number of occurrences of the highly concentrated types of interventions in the study area (the highest value for each category is shown in bold).

	ECUs					
TYPE	**GUAJIRA**	**VNSNSM**	**MAGDIQUE**	**SINU**	**DARIEN**	**TOTAL**
AHA	0	5	**10**	2	1	18
AHU	0	16	**89**	33	7	145
AHM	0	3	**146**	39	0	188
CAP	3	6	**33**	12	9	63
ROM	0	1	**37**	13	5	56
EMP	3	0	**23**	4	0	30
CYP	32	42	211	**349**	104	738
MUR	2	1	9	2	**27**	41
MAN	5	4	**14**	2	2	27
PUC	0	2	**10**	0	0	12
PUG	3	1	**11**	1	2	18
MMN	0	1	**17**	1	0	19
EDF	0	12	**39**	4	2	57
EDN	4	**56**	9	28	2	99
SUM	***52***	***150***	***658***	***490***	***161***	*1511*
AHB	**306**	83	62	**283**	**237**	971
***SUM* (*all 29 types*)**	382	269	803	845	443	2742

MAGDIQUE also concentrates the industrial and commercial activity in the CCCC because it comprises 61% of the interventions in the typologies MAN, PUC, and PUG. This evaluation is consistent with the socioeconomic character of the study area mentioned earlier, since MAGDIQUE contains three of the five most populated cities of the Colombian Caribbean (Barranquilla, Cartagena, and Ciénaga) as well as two harbor and industry hotspots, related to the current operational facilities of the region (DANE, 2012a, 2012b). It is worth mentioning that three maritime trade and joint infrastructure facilities are projected with approved environmental licenses in DARIEN.

MAGDIQUE has the biggest concentration of tourism-related interventions, not only for the typologies regarding the 3S tourism (EDF and MMN), but for those attributed to second residences (AHU and AHM), comprising 71% of the intervention count for these four typologies. Luxury settlements represent a type of infrastructure linked to floating population that coincide with tourist seasons on coastal zones (Barragán & de Andrés, 2015). Within the same category of tourism and recreation, the VNSNSM unit precedes with only one highly concentrated intervention, by accounting 57% of the nature tourism (EDN) occurrences. This may be attributed to the confluence of three natural parks in this unit with high proximity: Sierra Nevada de Santa Marta, Tayrona, and Los Flamencos, the last two being directly on the littoral. Finally, GUAJIRA is the only unit without any particular intervention being highly concentrated, although it accounts for one third of AHB, which is closely followed by SINU and DARIEN.

Despite of the huge amount of information gathered, the inventory had a critical limitation from the remote observation of the CCCC. Google Earth images and similar imagery services pose a difficulty for the identification of works or activities lacking a distinctive shape or requiring temporal analysis. Many of the intervention typologies cannot be easily discerned from an aerial perspective; such is the case for underground conduits (e.g., water conductions and pipelines), operation of irrigation districts, or beach nourishments. The latter ones are an example of the kind of intervention requiring time-series analysis for a proper recognition.

Several sources of information, like historical documents and narratives, inhabitants' testimonies, and observations of other remote sensing materials, may dominate as secondary source data. This information confirms that an important, but undefined, number of rigid coastal structures (particularly groins) built at the beginning of the twentieth century, have been completely destroyed by the sea. Little evidence of this situation could be recorded in the inventory, as shore erosion has rapidly reconfigured the aerial view of coastline profiles.

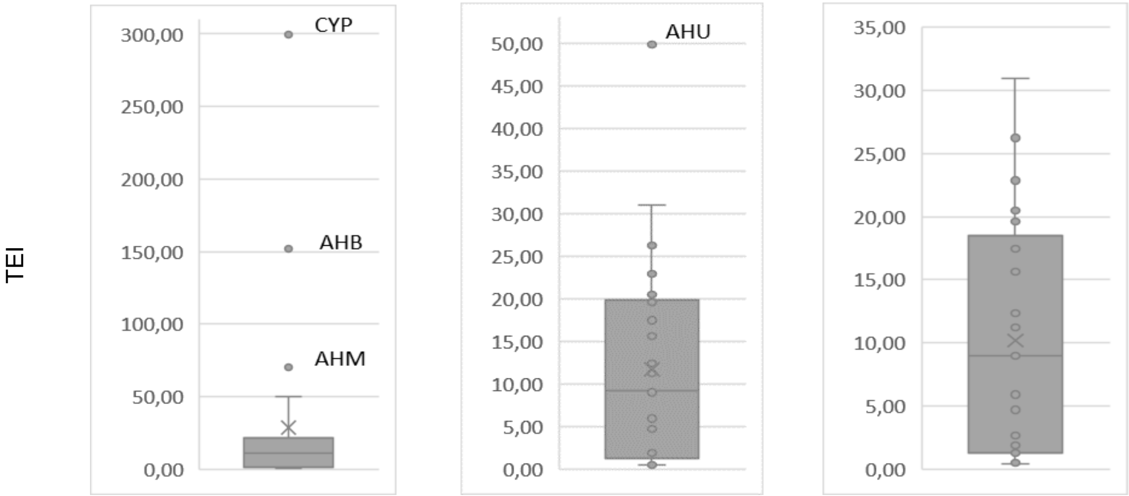
Another type of intervention that cannot be easily identified from images is submarine emissaries, a basic sanitation facility. This kind of intervention has been recognized as relevant in the coastal environment, such as in the case of marine strategy of the EU Directive 2008/56, which pinpoints the influence of these facilities in three of the good environmental state descriptors. Conversely, the typologies linked with drainage basin alterations and extensive land-use and livestock are not often associated with the coastal zone because they transcend their conceptual boundaries. However, the physical processes modeling watersheds establish a link with coastal morphology in terms of sediment supply (Correa & Restrepo, 2002; LOICZ, 2005; J. Restrepo, Escobar, et al., 2016). Therefore, the scope of the inventory was narrowed down to the legal definition of the coastal zone in Colombia and to the parameters at the temporal and spatial resolution of the available inputs.

3.4.2. Environmental impact of interventions with effect in the coastal zone

The frequency of an intervention's typology and its means to modulate the environmental impact associated with specific types, were a valuable result obtained from this inventory. The most relevant interventions in terms of frequency of appearance, the estimated UEI, and the corresponding TEI show clear patterns in the area. The application of Eq. 1 and 2 to the 29 coastal interventions demonstrated that the four types of interventions having the highest frequency coincide with those having the highest TEI, although their respective order is slightly different. However, among the ten most frequent typologies, only two are in the top ten interventions with the higher UEI. For example, low-density-settlements (AHB) exhibit the highest frequency in the CCCC, while ranking at the penultimate position of unitary impact (UEI ORD: 28); however, the total impact attributed to this typology in the study area ranks second among all 29 identified typologies. Although AHB depicts an exceptional case, other typologies support the premise that numerous occurrences of interventions with medium-to-low unitary impact can magnify the environmental effect (e.g., EDN, EDF, GRA, and AHM).

The "groins" (CYP) typology is one of the variants of the hard shore-protection structures that comprises over a third part of the overall TEI in the study area (36.3%). When combined, the values of CYP with AHB have a TEI of more than half of the overall impact estimated for all the CCCC (54.6%). An additional evaluation is that the majority of the overall TEI (85%) is attributed to only ten types of interventions, eight of them are among the most frequently occurring. The eighth and ninth intervention positions within the top ten of TEI correspond to inlet navigation channels (EMP) and seawalls (MUR), which represent each 2.5% of TEI. These types of interventions are variants of shore-protection structures, together with another two interventions in the top ten (CYP and ROM), which fall under the regional and national expertise for environmental licensing in Colombia (Pereira et al., 2018).

Considering the overall values of TEI by type of intervention as a descriptive statistic, the data distribution allowed a filtering analysis, depicted in Figure 3.3. The box plot of the TEI value for all 29 intervention typologies indicates that data distribution is asymmetrical (refer scenario A). A Tukey test revealed the presence of three extreme atypical values, corresponding to the typologies CYP, AHB, and AHM; they exceed three times the upper limit of the interquartile range (1.87 units of TEI). The box plot of the analysis without the extreme outliers (scenario A') confirms the presence of a mild atypical value, corresponding to the typology AHU, which exceeded the upper limit of 1.5 times the interquartile range. All outliers were removed from the sample to represent a more homogeneous distribution of the data in scenario B. The consideration of both scenarios (A and B) allows for a better understanding of the behavior of TEI values among all the intervention typologies, without the shadowing effect of the atypical values. In addition, this outlier analysis highlights AHB, AHM, and AHU as highly impactful interventions, which are not currently considered in the ELP. Instead, these typologies are regulated by the municipal land-use plans, which are the official urban planning instrument in Colombia. Consequently, a complementary role between EIA and territorial planning is demonstrated.



Scenario A. 29 types of interventions

Scenario A'. 26 types of interventions

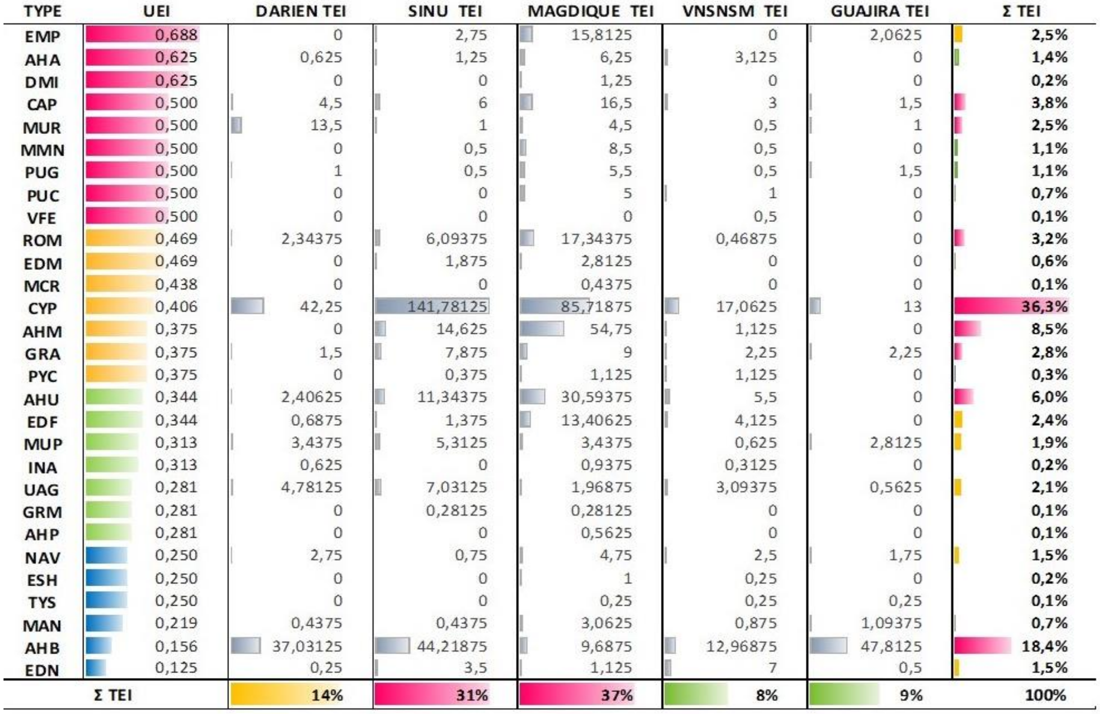
Scenario B. 25 types of interventions

Figure 3.3. Box plots for the overall TEI values, representing the asymmetric distribution of data (A), the distribution without extreme outliers (A'), and the distribution without extreme and mild outliers (B).

Therefore, Figure 3.4 expands on two of the represented scenarios, regarding the values of environmental impact estimated in the five ECU. The first column gathers the UEI values with a coded color, according to their respective quartiles. The bars on the columns for each ECU represent the respective TEI values. The final column of each scenario represents the proportion of the overall TEI attributed to each intervention's typology, with the same coded color for their respective quartiles. The last row in each scenario represent the percentage of TEI in each ECU according to the respective scenario. Meanwhile, the penultimate row of scenario B represents the percentage of TEI, when extracting the interventions with atypical values but according to the totals of scenario A.

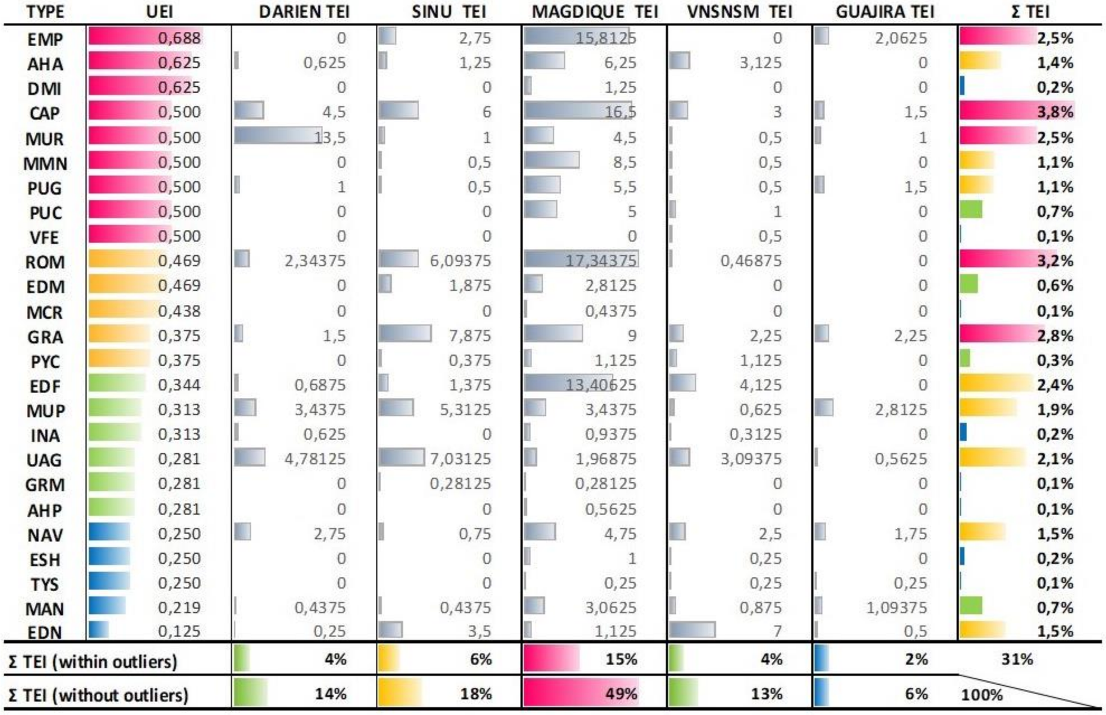
The results show that 31% of the overall TEI in the study area corresponds to the 25 types of interventions, with no atypical values of TEI. The other 69% is attributed to the typologies CYP, AHB, AHM, and AHU, and produces the shadow effect on the meaning of the other 25 types of interventions. The relevance of some interventions in certain ECU is masked until any interventions with outlier TEI values are removed (scenario B). This is the case for MUR in DARIEN; GRA, UAG, ROM, CAP, and MUP in SINU; EDN in VNSNSM; MUP, GRA, and EMP in GUAJIRA. The filtered representation of scenario B demonstrates how MAGDIQUE reflects the same tendency of the TEI for all the CCCC.

Scenario A.: 29 types of interventions



TYPE	UEI	DARIEN TEI	SINU TEI	MAGDIQUE TEI	VNSNSM TEI	GUAJIRA TEI	Σ TEI
EMP	0,688	0	2,75	15,8125	0	2,0625	**2,5%**
AHA	0,625	0,625	1,25	6,25	3,125	0	**1,4%**
DMI	0,625	0	0	1,25	0	0	**0,2%**
CAP	0,500	4,5	6	16,5	3	1,5	**3,8%**
MUR	0,500	13,5	1	4,5	0,5	1	**2,5%**
MMN	0,500	0	0,5	8,5	0,5	0	**1,1%**
PUG	0,500	1	0,5	5,5	0,5	1,5	**1,1%**
PUC	0,500	0	0	5	1	0	**0,7%**
VFE	0,500	0	0	0	0,5	0	**0,1%**
ROM	0,469	2,34375	6,09375	17,34375	0,46875	0	**3,2%**
EDM	0,469	0	1,875	2,8125	0	0	**0,6%**
MCR	0,438	0	0	0,4375	0	0	**0,1%**
CYP	0,406	42,25	141,78125	85,71875	17,0625	13	**36,3%**
AHM	0,375	0	14,625	54,75	1,125	0	**8,5%**
GRA	0,375	1,5	7,875	9	2,25	2,25	**2,8%**
PYC	0,375	0	0,375	1,125	1,125	0	**0,3%**
AHU	0,344	2,40625	11,34375	30,59375	5,5	0	**6,0%**
EDF	0,344	0,6875	1,375	13,40625	4,125	0	**2,4%**
MUP	0,313	3,4375	5,3125	3,4375	0,625	2,8125	**1,9%**
INA	0,313	0,625	0	0,9375	0,3125	0	**0,2%**
UAG	0,281	4,78125	7,03125	1,96875	3,09375	0,5625	**2,1%**
GRM	0,281	0	0,28125	0,28125	0	0	**0,1%**
AHP	0,281	0	0	0,5625	0	0	**0,1%**
NAV	0,250	2,75	0,75	4,75	2,5	1,75	**1,5%**
ESH	0,250	0	0	1	0,25	0	**0,2%**
TYS	0,250	0	0	0,25	0,25	0,25	**0,1%**
MAN	0,219	0,4375	0,4375	3,0625	0,875	1,09375	**0,7%**
AHB	0,156	37,03125	44,21875	9,6875	12,96875	47,8125	**18,4%**
EDN	0,125	0,25	3,5	1,125	7	0,5	**1,5%**
Σ TEI		**14%**	**31%**	**37%**	**8%**	**9%**	**100%**

Scenario B. 25 types of interventions (without CYP, AHB, AHM, and AHU)



TYPE	UEI	DARIEN TEI	SINU TEI	MAGDIQUE TEI	VNSNSM TEI	GUAJIRA TEI	Σ TEI
EMP	0,688	0	2,75	15,8125	0	2,0625	2,5%
AHA	0,625	0,625	1,25	6,25	3,125	0	1,4%
DMI	0,625	0	0	1,25	0	0	0,2%
CAP	0,500	4,5	6	16,5	3	1,5	3,8%
MUR	0,500	13,5	1	4,5	0,5	1	2,5%
MMN	0,500	0	0,5	8,5	0,5	0	1,1%
PUG	0,500	1	0,5	5,5	0,5	1,5	1,1%
PUC	0,500	0	0	5	1	0	0,7%
VFE	0,500	0	0	0	0,5	0	0,1%
ROM	0,469	2,34375	6,09375	17,34375	0,46875	0	3,2%
EDM	0,469	0	1,875	2,8125	0	0	0,6%
MCR	0,438	0	0	0,4375	0	0	0,1%
GRA	0,375	1,5	7,875	9	2,25	2,25	2,8%
PYC	0,375	0	0,375	1,125	1,125	0	0,3%
EDF	0,344	0,6875	1,375	13,40625	4,125	0	2,4%
MUP	0,313	3,4375	5,3125	3,4375	0,625	2,8125	1,9%
INA	0,313	0,625	0	0,9375	0,3125	0	0,2%
UAG	0,281	4,78125	7,03125	1,96875	3,09375	0,5625	2,1%
GRM	0,281	0	0,28125	0,28125	0	0	0,1%
AHP	0,281	0	0	0,5625	0	0	0,1%
NAV	0,250	2,75	0,75	4,75	2,5	1,75	1,5%
ESH	0,250	0	0	1	0,25	0	0,2%
TYS	0,250	0	0	0,25	0,25	0,25	0,1%
MAN	0,219	0,4375	0,4375	3,0625	0,875	1,09375	0,7%
EDN	0,125	0,25	3,5	1,125	7	0,5	1,5%
Σ TEI (within outliers)		4%	6%	15%	4%	2%	31%
Σ TEI (without outliers)		14%	18%	49%	13%	6%	100%

Figure 3.4. Values of the unitary (UEI) and total (TEI) environmental impacts estimated for the CCCC. Scenario A: all 29 identified intervention typologies; Scenario B: intervention typologies without atypical values. Distribution of data in quartiles: Q1 in blue, Q2 in green, Q3 in yellow, and Q4 in red.

In Figure 3.2, SINU present a higher proportion of interventions with respect to MAGDIQUE, with only a 2% difference. However, this order is reversed when comparing the TEI values, with MAGDIQUE leading with 37% and SINU following closely with 31%. The gap between both units is accentuated when the outliers in scenario B are removed, leaving MAGDIQUE with 49% of the representation and SINU with 18%. This suggest that, while MAGDIQUE and SINU each hold over one third of the overall TEI, without the shadowing typologies, MAGDIQUE accounts for almost half of the overall TEI, and SINU drops to less than the fifth part. Judging by the high concentration of the CYP typology in SINU during the inventory, most of the impact in this unit is from hard shore-protection structures (e.g., groins). Conversely, the increased representation of MAGDIQUE is attributed to a combination of interventions with UEI values in the third and fourth quartiles, while the relevant ones in SINU have UEI values in the second and third quartiles.

Finally, over one third of the overall TEI in the area is attributed to the typology CYP, not only because its UEI value is moderate-to-high (Q3), but also because it exhibits the second highest frequency of occurrence from all interventions in the area. The other three typologies comprising the atypical values of TEI belong to the category of human settlements, with the isolated populated areas (AHB) holding the second position in TEI rank, despite having a low UEI (Q1). The remaining two types are luxury housing, with and without private pier, whose values are rather similar with a joint representation of ~15% on the overall TEI for the study area. In this case, frequency cannot be solely responsible because the UEI value of AHU is medium-to-low (Q2), while the case with a private pier (AHM) lies in Q3, due to their direct effect on coastal morphology.

It is worth noting the high level of littoral armoring in SINU and DARIEN, given their low infrastructure and economic development, which do not justify the high level of hard structures. One explanation is based on Rangel-Buitrago et al. (2017), who state that most of the protective works were carried out as private efforts to protect tourism-related infrastructure, farming lands, and luxury rural housing. Indeed, analysis of coastal erosion in this area pinpoints a proliferation and ineffectiveness of shore-protection works, judging by the rising erosion rates, now approximately 3 m/yr (Correa et al., 2007, 2005; Paniagua-Arroyave, Correa, Anfuso, & Adams, 2018; Prüssmann, 2011; Rangel-Buitrago et al., 2015). Substantially, Correa and Vernette (2004) reported that out of the 150 rigid shore-protection structures in this area, only ten have proven effective. The remainder was useless and even induced an accelerated erosion. Overall, these situations suggest that the national government may be unaware of the experiences of countries with broader tracking in coastal management, e.g., Cuba, which recognizes hard shore-protection structures as an environmental violation (Pereira et al., 2018).

Ultimately, this also indicates that the effects of hard structures for shore-protection remain overestimated with respect to controlling and mitigating littoral erosion, despite their widely debated effectiveness, given their side effects and other types of measures (Botero et al., 2013; Correa & Gonzalez, 2000; Pranzini et al., 2015; AT Williams et al., 2018). Within the alternative measures to counteract shore erosion, the relocation of existing infrastructure and human values, also known as managed realignment, is increasingly gaining worldwide acceptance (Rangel-Buitrago, de Jonge, & Neal, 2018; AT Williams et al., 2018). Given the high geomorphological instability of the Colombian Caribbean and the projections of at least 1 m sea level rise in the following 100 years (IPCC, 2014), immediate or programed retreat figures as a wise strategy to be considered in territorial planning.

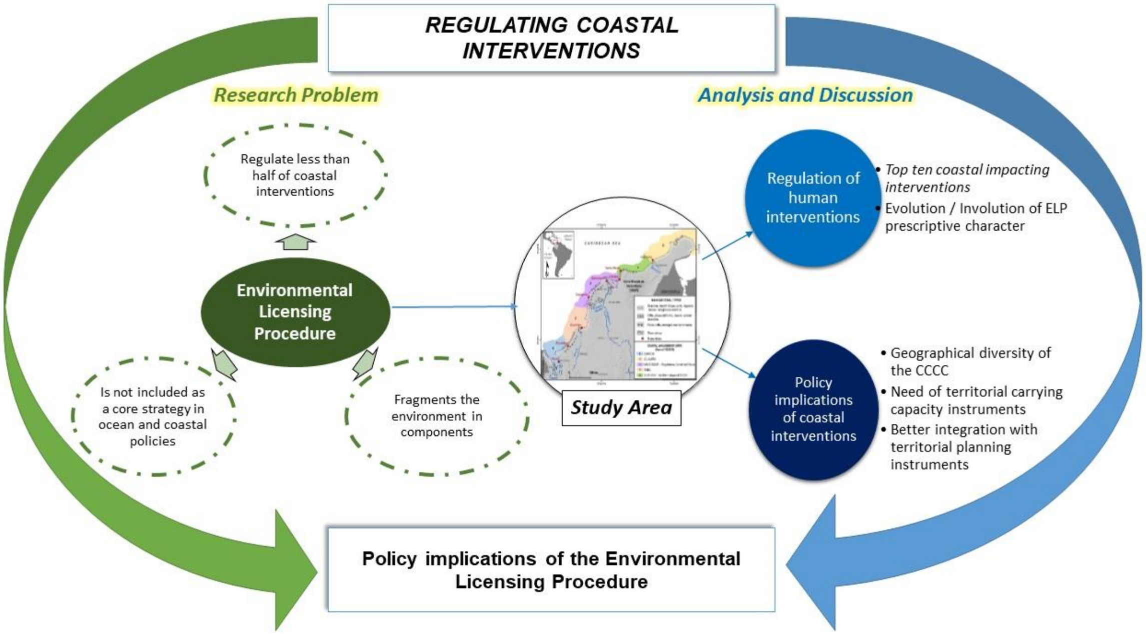
3.5. Conclusions

The exhaustive inventory of coastal interventions presented allows certain patterns in the CCCC to be highlighted. Initially, almost half of the different typologies of coastal interventions are present in the study area, which could be understood as a moderate variety of activities on the coasts, despite its long extension. Within the five ECU, the MAGDIQUE unit has the most diverse composition of activities, although the SINU unit represents the majority of total interventions. Conversely, GUAJIRA has the lowest diversity of interventions, which are highly concentrated in low density human settlements. These findings confirm the strong relationship between urban development and the diversity of the economic activities on the coast. In addition, the high occurrence of human settlements and coastal protection structures, compared with some larger interventions such as ports or aquaculture ponds, demonstrates the importance of doing an inventory of these small interventions. This exercise could perhaps be enriched with in situ field work to reinforce the hypotheses about the repercussions of human perturbation on the morphological evolution of the Earth’s surface. In a nutshell, it is important for environmental management policies to not only account for big coastal interventions, but also the frequency and distribution of small ones.

Regarding the environmental impact over the natural processes influencing the coastal zone, certain aspects are important to highlight. One of the main limitations of EIA is the evaluation of a single intervention without the inclusion of impacts from and to other interventions in the influence area. This study demonstrated the importance of evaluating the UEI, which is as important as assessing the sum of the impacts of the same kind of intervention (TEI). Although this research comprehends an extensive coastal area, it could also be applied to smaller areas and the results will be similar, as long as the analysis is done at a regional scale. Moreover, the box plot analysis demonstrated that extreme and mild outliers in the data can minimize the real effect of the majority of coastal interventions, forcing misevaluations of their real environmental impact. Therefore, the results of this study stress the need to control the anthropogenic effect of coastal interventions over the natural processes based on an alternative approach of EIA.

CHAPTER IV

Regulating human interventions in coastal areas: policy implications of the environmental licensing procedure



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4.1. Abstract

Environmental impact assessment (EIA) is the preferred tool for governments to mitigate the negative effects of economic development. In the same way, environmental licensing procedure (ELP) is the documental or bureaucratic practice that enforces EIA implementation. Although EIA could be used in any environment, coastal areas pose a particular challenge because of their special nature as the interface between land and sea. Therefore, this study evaluates the ELP in Colombia with regard to coastal areas to extract policy implications for coastal and ocean planning and regulation worldwide. Starting from an exhaustive inventory of human interventions in the Caribbean Coast of Colombia (CCC) and their unitary and total environmental impact, the ELP was analyzed within the current legislation and national policies for coastal and ocean areas. The study finds that the ELP currently regulates less than half of the types of interventions impacting the coastal zones, and the number of the interventions covered in each new legislative reform consistently decreased over time. Moreover, three main policy implications of ELP for coastal areas were extracted. These policy implications focused on the geographical diversity of the tropical coastal zones as well as the need for territorial carrying capacity instruments and better integration with territorial planning instruments. The conclusions highlight that the ELP in Colombia, as in other countries, is not included as a core strategy of the national ocean and coastal policies, generating a gap between technical and policy decision making. Accordingly, ELP articulation should be improved by including territorial planning instruments to cover the demand for the environmental control of coastal interventions and reinforce workflows using novel methods to assess the breadth and length of coastal dynamics. This paper reflects the need for further analysis of ELP in countries with coastal zones, helping improve policy-making regarding EIA. The evaluation framework proposed in this paper can also be applied in other tropical developing countries.

4.2. Introduction

Although the environmental impact assessment (EIA) is the main governmental tool for environmental control, its application in coastal zones poses substantial challenges because of their special nature as the interface between land and sea (Frihy, 2001; Fuentes-Bargues, 2014; Nordhaus, Roelke, Vaquer-Sunyer, & Winter, 2018). Even though EIA application in coastal environments have been analyzed in several countries (e.g. Cuba, Portugal, Spain, Sri Lanka, New Zealand, and Egypt, among others), the policy implications of this tool have not been studied in depth (CITMA, 1999; Enríquez-de-Salamanca et al., 2016; Frihy, 2001; Fuentes-Bargues, 2014; GORC, 1997; Guerra et al., 2015; Hapuarachchi et al., 2016). In Colombia, the challenge of controlling the environmental impact of coastal interventions is accentuated by an insufficient environmental licensing procedure (ELP), which presents flaws in coastal delimitations during the impact assessment and lacks a screening stage for certain interventions that may require a robust valuation of the impacts over natural processes (Pereira et al., 2018). Therefore, identifying the context and evolution that have created this lax environmental regulatory framework in Colombia should be of major interest to establish its implications on the management of coastal areas in tropical developing countries.

A primary source for the problem statement relies on coastal regulatory frameworks and policies. From the legal perspective, Milanes (2018) revealed that technical terms and corresponding policies for coastal boundaries in several countries are backed by their respective coastal laws. For instance, the regulatory framework of Cuba exhibits a high level of awareness for coastal environments when evaluating the impact of human interventions (Pereira et al., 2018). As another example, the national government of the UK has separately transposed EIA directives by marine and terrestrial projects through the Marine Work Regulation and the Town and Country Planning Act, respectively (Lonsdale et al., 2017). Despite neither being an island nor a peninsula, Colombia has three coastal zones within the Caribbean Sea (continental and insular) and Pacific Ocean that should obligate the nation to implement particular care for its coastal environment (Avella et al., 2009). However, Colombia has no coastal law or similar high-level regulations, and its legal code for coastal matters relies on a few specific decrees and two nonbinding policies with limited national implementation (Botero & Marin, 2018; CCO, 2017; MMA, 2000).

Without substantial support for environmental management, the two nonbinding ocean and coastal policies are the only regulatory framework covering coastal interventions in an integrated manner. The oldest policy, formulated by the Ministry of Environment in 2000 (MMA, 2000), includes a specific program to promote the sustainability of economic sectors, which emphasizes the following: 1. fisheries and aquaculture, 2. agro-livestock and agro-industry, 3. mines and energy, 4. ports and maritime transport, 5. coastal infrastructure, 6. industry and trade, and 7. tourism and recreation. Thereafter, the Colombian Oceanic Commission approved a National Coastal and Oceanic Policy in 2007, which proposes actions to prevent and control the environmental impacts of certain economic activities (CCO, 2007). However, the updated version of this policy, approved in 2017 (CCO, 2017), does not include a strategy or program related to the environmental impact of coastal and marine activities; the policy only makes rhetorical mentions within economic development actions.

In the general context, several countries have adopted environmental licenses as a policy instrument of prevention, where the state legally intervenes in actions of public or private interest that may cause environmental degradation (Burgel et al., 2017; Jaskoski, 2014; Monteiro & da Silva, 2018). Similarly, Villarroya et al. (2014) studied nine Latin American countries, including Colombia, and indicated that the environmental license depended on the mitigation of the predicted negative impacts and/or fulfillment of additional requirements set by the licensing authority. Therefore, the ELP is considered to be the legal and administrative protocol to bind and legitimate the EIA in a given country, where a petitioner is entitled with a permit to execute a project, work, or activity according to the outcome of the environmental assessment. Despite being a documental or bureaucratic procedure, the ELP operate on technical principles of EIA best practices regarding the protocol for screening the types of intervention requiring an impact assessment, scoping the environmental study, examining project alternatives, approving or denying licenses, or following up on approved licenses (IAIA & IEA, 1999; Pereira et al., 2018). Therefore, the ELPs correspond to a legal action, whereas the EIA involve the activities that provides the technical input for the decision-making process.

This paper contrasts the environmental impact estimated for the types of interventions inventoried in the Caribbean Coast of Colombia (CCC) with the current environmental licensing regulatory framework in the country. Based on these findings, implications for the national coastal policy are highlighted to provide recommendations to improve the ELP and the implementation of integrated coastal and ocean management actions in Colombia and other tropical developing countries.

4.2.1. ELP context in Colombia

The Ministry of Environment in Colombia was created in 1993, a year in which the country entered the worldwide path of assessing and controlling the effects caused by human interventions in natural and human environments. Consequently, the ELP was established by Decree 1753 of 1994, regulating 42 sectors and activities; the consequent updates are detailed in Section 4.4.1 (Toro et al., 2010). In addition, environmental competences in Colombia, including the ELP, are shared between the central and regional levels of authority. Therefore, projects, works, and activities are equally distributed according to their features and regulated by the National Authority of Environmental Licensing at the central level and the respective Autonomous Corporation at the regional level (Pereira et al., 2018; Toro et al., 2010).

As part of the ELP, the Ministry of Environment has established guidelines for the preparation and execution of environmental studies, commonly called terms of reference (ToR). If the ToR for a given project or activity has not been issued, the competent environmental authority could specifically formulate the ToR for each case. The updates to these guidelines are executed according to the regulatory and technological evolution in each regulated sector and a review of the demand for projects that required a license from the environmental authorities. For example, with the issuance of Law 1682 of 2013 (commonly called “the Infrastructure Law”), a general update of all ToR for the infrastructure sector was enforced according to the new guidelines. Consequently, the ToR have been influenced by the regulatory developments of economic sectors rather than the necessity to protect a certain area of environmental importance or a critical natural process.

Since 2006, more than 40 ToR have been created by the Ministry of Environment, 84% of which refer to the elaboration of environmental impact studies, namely, 5% for management plans and 11% for the environmental diagnosis of alternatives. These guidelines are mostly addressed to petitioners of environmental licenses and are used by the authorities during the revision and quality assessment of the studies. Since the establishment of the ELP, the evaluation of human impacts has been designed to divide the environment into components corresponding to a fragmented-oriented approach. After 25 years and several updates to the regulation, Colombia must change its approach regarding how impact assessments are performed by shifting to a process-oriented analysis of natural flows within a type of environment and its neighboring connections (Pereira et al., 2018).

4.2.2. Study area: The CCC

Derived from the aforementioned environmental policy (MMA, 2000), Decree 1120 of 2013 officially delineated three coastal zones in Colombia: the Continental Caribbean Coast, Insular Caribbean Coast, and Pacific Coast. Within this division, the same decree defines environmental coastal unit (ECU) to segment the study area into the following five gross areas: Darien, Sinu, Magdique, VNSNSM, and Guajira. The boundaries of these units in the CCC are depicted in Figure 4.1, in addition to the main morphological characteristics.

The approximately 1,700 km of shoreline of the study area alternates between deltaic plains and low coasts, with high coasts of mountainous segments (Correa & Pereira, 2019). The low-lying coasts contain beaches, sand barriers, and spits normally associated with lagoons and mangrove swamps. The high-lying coasts are represented by cliffs of sedimentary rocks in the northernmost end (La Guajira) and in the middle (between Barranquilla and Cartagena City). Furthermore, the cliffs surrounding the SNSM massif and the southernmost end (Panama border) comprise most resistant igneous and metamorphic rocks (DIMAR-CIOH, 2013). Between the deltas of the Magdalena and Atrato rivers, the coast features Holocene marine terraces influenced by the mud diapiric phenomena (Duque-Caro, 1984; Mendivelso et al., 2010; Vernette, 1989).

According to the national statistics (DANE, 2012a, 2012b), the CCC has large areas (the departments of Choco, Cordoba, Sucre, Magdalena, and La Guajira) with socioeconomic development based on the primary sector. The industries and third sector economic activity are highly concentrated in the densest areas between Cartagena and Santa Marta and represent less than one-third of the coastline. Furthermore, the most populated cities of the study area (i.e., Barranquilla, Cartagena, Santa Marta, Cienaga, and Riohacha) represent one-sixth of the most populated cities in Colombia. These cities comprise a little more than 6% of the total national population (DANE, 2012a). This data suggests that despite possessing the three coastal zones (i.e., Pacific, Insular, and Continental Caribbean), Colombia does not represent the worldwide trend of human concentration in coastal cities (Barragán & de Andrés, 2015).

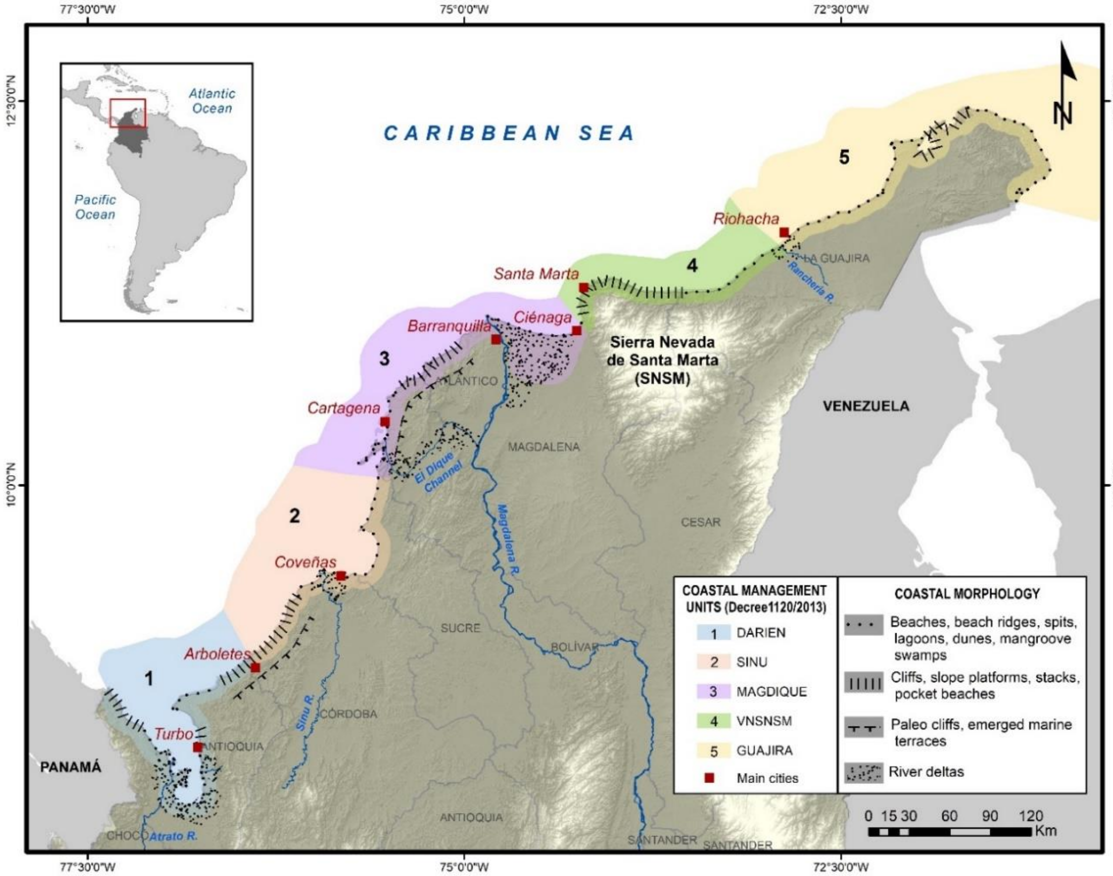


Figure 4.1. Study Area: The CCC. Adapted from the study by Correa and Pereira (2019). Magdique refers to the unit Magdalena-Canal del Dique, and VSNSM refers to the unit of the northern slope of the SNSM massif.

4.3. Methods

First, a list of typologies of human interventions was compiled from the structure of coastal uses and activities proposed by Botero et al. (2014) for tropical countries. The list defined more than 50 types of interventions, that is, land transformation, infrastructure, and joint facilities, whose placement could disturb the natural processes influencing the coastal morphology (Pereira et al., 2018). Next, all the human interventions over the CCC covering more than 3,400 km2 of coastal area were identified by observing open source satellite imagery (i.e., the majority of the imagery was from Google Earth, and alternative imagery services such as Nokia, Bing, and ESRI were also referenced). Moreover, a code system with three letters was defined to represent the type of intervention and ease the identification, compilation, and analysis of the vast quantity of human interventions found.

After observing the study area, a simplified EIA was performed on each typology of human intervention found. First, the quantity of interventions found in each typology was counted to obtain the frequency of occurrence per type and organize the interventions from the most to least frequent. Second, the unitary environmental impact (UEI) of each typology was calculated on the basis of four attributes: extension, intensity, reversibility, and persistence. The values for extension and intensity range between 1 and 12. The values for reversibility and persistence range between 1 and 4 according to the scores defined by Conesa (2006). Third, the total environmental impact (TEI) of each typology was calculated through the multiplication of its UEI with the respective frequency of occurrence on the study area.

Simultaneously, a deep review of the ELP evolution in Colombia was performed by referring to the study by Toro et al. (2010). Appendix IV gathers the list of regulations cited along this work. Based on the legal framework from 1993 to 2017, approved by the Ministry of Environment, each typology of project, work, and activity governed by the ELP was identified along each of the five decrees that have regulated the matter in Colombia: Decree 1753 of 1994, Decree 1728 of 2002, Decree 1180 of 2003, Decree 1220 of 2005, and Decree 2041 of 2014, which are currently compiled in Decree 1076 of 2015. Although several projects, works, and activities regulated by these decrees are not specific to coastal areas, the codes of the human interventions identified as having the greatest impact in the CCC established the link in the record.

Finally, the policy implications of the ELP in coastal areas were extracted according to the values of UEI and TEI for each typology estimated in the study. The two national policies for coastal and ocean areas in Colombia were reviewed to identify actions that incorporated the ELP as a strategy to reduce the negative effects of the human interventions in natural processes. Moreover, the principles of integrated coastal zone management, marine spatial planning, land-use planning, and integrated watershed management defined by Botero et al. (2016) were analyzed to frame the ELP in accordance with these well-known planning tools.

4.4. Results and Discussion

4.4.1. Regulation of human intervention in the CCC

Twenty-nine interventions were identified in the study area among the nearly 50 types of projects, works, and activities that affected the coastal zone considered by Botero et al. (2014) and adapted by Pereira et al. (2018). Table 4.1 summarizes the results of the most relevant interventions in terms of frequency, UEI, and TEI. The values regarding the frequency represent the number of occurrences of each intervention typology, the proportion it comprises in the total account of interventions and the occurrences' order from the most to least frequent. In the respective segments for the UEI and TEI, the first column presents the estimated values, the second column presents the proportion of the environmental impact estimated within the sum of all identified interventions, and the third column presents the rank of each typology within all 29 interventions.

The most frequent human interventions in the CCC were the low-density settlements (AHB) because less than 30% of the population of Colombia lives in coastal areas, with the main cities and towns (high-density settlements) located in mountainous areas (Avella et al., 2009). Therefore, although this intervention typology had almost the lowest UEI (28th), it had the second biggest TEI in the study area, indicating the importance of frequency of the impact assessment for a broad territory. Conversely, the three interventions with highest UEI values were not included in Table 4.1 because their frequencies of occurrence were lower than those of the top 10 of the highest TEI values. Interventions linked to natural tourism had high frequencies in the study area, but their UEI was among the lowest within the identified human interventions and, consequently, had a medium TEI (14th).

Table 4.1. Top 10 human interventions impacting the CCC.

TYPOLOGY	CODE	FREQUENCY			UEI			TEI			REGULATED BY ELP
		#	%	ORD	units	%	ORD	units	%	ORD	
Low-density settlements	AHB	971	35.40%	1st	0.16	1.40%	28th	15.,7	18.40%	2nd	NO
Groins	CYP	738	26.90%	2nd	0.41	3.60%	13th	299.8	36.30%	1st	YES
Luxury settlement with pier	AHM	188	6.90%	3rd	0.38	3.30%	14th	70.5	8.50%	3rd	NO
Luxury settlements	AHU	145	5.30%	4th	0.34	3.10%	17th	49.84	6.00%	4th	NO
Natural tourism	EDN	99	3.60%	5th	0.13	1.10%	29th	12.38	1.50%	14th	NO
Road infrastructure	CAP	62	2.30%	6th	0.5	4.40%	4th	31	3.80%	5th	YES
Farming and livestock	UAG	62	2.30%	7th	0.28	2.50%	21st	17.44	2.10%	11th	NO
Aquaculture	GRA	61	2.20%	8th	0.38	3.30%	15th	22.88	2.80%	7th	YES
Sun, sea and sand tourism	EDF	57	2.10%	9th	0.34	3.10%	18th	19.59	2.40%	10th	NO
Breakwaters	ROM	56	2.00%	10th	0.47	4.20%	10th	26.25	3.20%	6th	YES
SUM			89%			30%			85%		YES (40%)

Note: ORD denotes order or rank within all the typologies in the respective variable.

Notably, the data indicate that the majority of interventions with high UEI are also those with high frequency and thereby high TEI. Two groups of interventions are remarkable: coastal protection works and luxury settlements. Coastal protection works comprise groins (Freq: 2nd; UEI: 13th; and TEI: 1st) and breakwaters (Freq: 10th; UEI: 10th; and TEI: 6th), which have been largely established by the scientific literature as high-impact activities for coastal areas (AT Williams et al., 2018). Luxury settlements have received the opposite scientific attention, that is, the negative effects of luxury settlements over coastal processes and the deepest impacts of those settlements with their own piers (Freq: 3rd; UEI: 14th; TEI: 3rd) have rarely been studied. This invisibility was transferred to the regulation, as presented in the last column of Table 4.1. Within the five intervention typologies with highest TEI, only groins (TEI: 2nd) and roads (TEI: 5th) are regulated through the ELP; the remaining unregulated typologies (AHB, AHM, and AHU) total 32.9% of the overall environmental impact on the CCC.

Although previous publications have already registered the evolution of the regulatory framework of the Colombian ELP, no studies have analyzed the human interventions affecting the coast. For instance, Toro et al. (2010) presented a detailed list of sectors and economic activities requiring an environmental impact study according to the decrees enacted for the national environmental system from 1994 to 2007. As an updating exercise, Table 4.2 contains the list of projects, works, and activities under environmental licensing in Colombia presented by Toro et al. (2010), with two additional columns: one column for Decree 2041 of 2014 (currently in force) and the other column for the codes representing the interventions that affected the coastal areas.

Looking at the top ten interventions of Table 4.1 in Table 4.2, the typologies of human settlements (AHB, AHM, and AHU) outstand because they were once included in the legal code for the ELP. The construction of blocks of flats and housing were under the ELP within decrees 1753 of 1994, 1728 of 2002, and 1180 of 2003, but it was excluded from Decree 1220 of 2005. Other typologies with a similar regression in the environmental regulatory framework are within the category of tourism (EDN) and recreation (EDF). The construction and operation of tourist resorts and leisure/sport premises were delineated in the ELP in decrees 1753 of 1994 and 1180 of 2003 but excluded from Decree 1220 of 2005. This activity may also comprise the typologies of luxury settlements if considered as second residencies, which is a variant of the 3S tourism (Barragán & de Andrés, 2015).

The most impacting typologies within the category of basic activities (UAG and GRA) were once regulated in decrees 1753 of 1994 and 1728 of 2002. Both decrees include livestock, fish, and poultry farming as well as intensive flower cultivation, a variant of farming. The only economic activity in Decree2041 of 2014, barely related to these typologies, refers to the introduction of foreign species, subspecies, breeds, and wild varieties of flora and fauna, which were also under decrees 1753 of 1994 and 1220 of 2005. The remaining types of interventions with the greatest impact regarding shore protection structures (CYP and ROM) and lineal infrastructure (CAP) are considered in Decree 2041 of 2014 and in decrees 1753 of 1994 and 1220 of 2005.

Overall, the results of Table 4.2 reveal how the regulatory framework in a country such as Colombia has evolved from being more restrictive to having a medium level of restriction and how it has passed through an extremely unrestrictive period from 2002 to 2005. The first decree in 1994 included more than 42 sectors/activities. This number was reduced to 22 following the update in 2002, and the lowest number was 7 in the Decree of 2003. The updated decree in 2005 increased the amount of sector/activities to 21, and the currently enforced decree has maintained a similar figure, although not exactly the same interventions. Accordingly, some interventions such as human settlements are unregulated by the ELP.

Table 4.2. Evolution of the prescriptive character of the environmental licensing of projects, works, and activities in Colombia, with emphasis on coastal areas.
Updated and complemented from the study by (Toro et al., 2010)

	Activities governed by EIA	**Decree 1753 (1994)**	**Decree 1728 (2002)**	**Decree 1180 (2003)**	**Decree 1220 (2005)**	**Decree 2041 (2014)** [a, b]	**CODE**[d]
1	Cemetery construction	X[c]	X	X[c]			-
2	Construction of premises for storage and distribution of food	X	X	X[c]			-
3	Construction of blocks of flats and housing premises	X[c]	X	X[c]			AHB AHM AHU
4	Hospital construction	X[c]	X	X[c]			-
5	Dam and reservoir construction	X	X		X		-
6	Construction of water supply line systems	X	X				-
7	Construction of mass transport systems	X[c]	X	X[c]			-
8	Construction and operation of wastewater treatment systems (>200000 users)	X			X	X	-
9	Construction, modification, fitting and operation of terminals for ground transportation of passengers and goods	X[c]	X	X[c]			-
10	Construction and operation of tourist resorts and leisure and sport premises	X		X[c]			EDN AHU AHM
11	Construction and operation of electrical power stations; exploration and use of polluting alternative energies; cable laying of transmission lines	X			X	X	-
12	Construction and operation of irrigation and/or drainage systems	X			X	X	UAG
13	Construction and operation of premises for storage, treatment, and/or final disposal of dangerous waste.	X			X	X	-
14	Storage of dangerous substances with the exception of hydrocarbons	X			X	X	-
15	Construction and operation of sanitary landfills.	X			X	X	-
16	Maritime and port sector: Construction, extension, and operation of seaports; Deepening dredging; Construction of breakwaters, channels and hydraulic fills; beach stabilization and coastal waterways; Artificial creation of beaches and dunes	X			X	X	ROM CYP
17	Construction, modification and operation of airports	X			X	X	CAP
18	Commercial game and establishment of wild animal farms	X			X	X	-
19	Introduction of foreign species, subspecies, breeds and wild varieties of flora and fauna	X			X	X	UAG GRA
20	Livestock, fish and poultry farming	X	X				
21	Genetic manipulation and production of microorganisms	X	X				-
22	Intensive flower cultivation	X	X				UAG
23	Design and establishment of shopping centers and leisure areas.	X	X				-
24	Service stations, and fuel deposits and packaging centers	X	X				-
25	Generation of nuclear energy	X			X	X	-
26	Timber and furniture manufacture	X	X				-
27	Paper manufacturing, printing shops and publishing houses	X	X				-
28	Manufacture of foodstuffs	X	X				-
29	Manufacture of metallic products, machinery and equipment	X	X				-
30	Textile manufacture, garments and leather	X	X				-
31	Manufacture of basic metals	X	X				-
32	Public works in the railway network.	X			X	X	-
33	Public works in the national waterway network: Construction of ports; Closing of active wetlands; Deepening dredging in navigable channels and delta areas; Construction of breakwaters	X			X	X	ROM

34	Road network projects: Construction of roads; Construction of minor roads; Construction of tunnels and their approach roads	X			X	X	CAP
35	Pesticide importation and production	X			X	X	-
36	Forest exploitation projects	X					-
37	Reforestation and forestry	X					-
38	Project affecting National Natural Parks	X			X	X	-
39	Mining, exploitation: Coal; construction materials; metals and precious stones; other minerals	X	X		X	X	-
40	Hydrocarbon sector: Seismic exploration; exploratory drilling; hydrocarbon exploitation, transport and piping; delivery terminals and transfer stations; construction and operation of oil refineries	X			X	X	-
41	Basic chemical industrial sector: Manufacture of basic mineral-based chemical substances; manufacture of alcohols; manufacture of inorganic acids and their oxygenated compounds; manufacture of explosives, gunpowder, and fireworks	X			X	X	-
42	Projects requiring water transfer between hydrographic basins	X			X	X	-
43	Construction and operation of facilities for the storage, treatment, use (recovery/recycling) and/or final disposal of Waste Electrical and Electronic Equipment (WEEE) and waste batteries and/or accumulators					X	-
44	Construction and operation of facilities for the storage, use, recovery and/or final disposal of waste or hazardous waste, and the construction and operation of security landfills for hospital waste					X	-

[a] This decree contains the same list of sectors and economic activities under ELP as the previous update (Decree 2820 of 2010).
[b] Compiled in the Unique Environmental Decree 1076 of 2015.
[c] Environmental license is not required when the land-use plan approves the project location.
[d] Based only on the top 10 typologies presented in Table 4.1

Regarding the instruments to operate the ELP in Colombia, the 43 ToR formulated by the Ministry of Environment since 2006 (ANLA, 2017; Toro et al., 2010) cover nearly half of the coastal interventions and leave 6 of the 10 most frequent and impacting types of interventions inventoried (AHB, AHM, AHU, EDN, UAG, GRA, and EDF) without guidelines. Furthermore, these guidelines are extremely generic for the assessment approach in which they are framed. Toro et al. (2010) already indicated that all ToR in Colombia are alike, without substantial specificity in the type of intervention, despite being formulated by sectors or economic activities. Additionally, although the impacts' attributes better correspond to the behavior of natural processes, rather than project design, the conventional ELP remains oriented by type of intervention instead of the type of environment (Pereira et al., 2018).

The most recent editions of this ToR have progressively aggregated the requirements regarding operational management protocols (e.g., ecosystem services, compensation, and environmental economic assessment). However, their weakness remains regarding neither deepening the project discriminations nor providing instruction on the particularities of the type of environments to be perturbed. For example, although over 60 roads have been placed within the CCC, the ToR for the alternative diagnosis of linear infrastructure formulated in 2006 makes no distinction regarding coastal settings (Resolution 1275 of 2006). Similarly, the ToR formulated in 2013 for conducting environmental impact studies of road construction added requirements of analysis for management protocols; however, no instructions are given regarding particular types of environments. The subsequent update of this type of ToR in 2015 referred to roads and tunnels and integrated a caption about marine coastal water quality within the technical requirements on the abiotic component (Resolution 0751 of 2015). In addition, the representation of coastal processes remains obtuse for characterizing the influence area of roads in the littoral environment and their eventual follow-up. Therefore, this example highlights the urgency to develop a methodological approach for defining technical criteria regarding the susceptibility of coastal systems to the effect of human interventions to support the ELP in any country.

Another regulatory framework linked to the ELP is the implementation of national environmental geographic data storage models. In Colombia such database has been implemented by the National Agency of Environmental Licensing in 2012, with the following updates: Resolution 1415 of 2012, Resolution 0188 of 2013, and Resolution 2182 of 2016. The model aims to input data into the internal information system of the environmental authorities from environmental license applications and follow-up reports of all licensed projects under their competence (Solarte, 2017). Therefore, the national information system is supplemented by individual and private efforts and does not rely only on public funding for collecting and systemizing georeferenced environmental data. However, this advanced data model may be considered to be insufficient to gather the specificity of the marine coastal environment under disturbance by human interventions.

The data model is consistent with the generic structure of ToR for preparing environmental impact studies, where the environment is segmented into components. Therefore, the 242 feature classes of the model are distributed in approximately 12 generic themes, resembling groups of components (i.e., biotic, abiotic, socioeconomic) and management programs (i.e., compensation, environmental zoning, and risk management). Within this structure, the marine and coastal elements are limited to 24 feature classes distributed in two components: biotic-continental-coastal and marine. Marine was added in the most recent resolution that updated the model, which suggests an increasing awareness in Colombia regarding the role of and challenges posed by human interventions in the marine context.

4.4.2. Policy implications of coastal interventions

In a broad sense, certain policy implications for an integrated coastal management could be extracted from the environmental assessment, discussed in Section 4.4.1. First, Table 4.3 presents the extensive geographic diversity of interventions among coastal regions, implying that the ELP should recognize these regional particularities. As demonstrated, coastal interventions are not uniformly distributed in coastal areas, neither by the number of occurrences nor by typological diversity. Additionally, the Colombian example shows that Guajira unit comprises the fewest typologies and second fewest interventions inventoried, and Magdique presented high accounts of interventions comprising the highest number of typologies within all ECUs. An explanation for this pattern may be that Guajira has one of the lowest human development indexes in Columbia and largest indigenous population of the CCC (DANE, 2012a), implying fewer human interventions and more pristine landscapes. Magdique has the highest concentration of human population, industrial infrastructure, and active commerce within the CCC but the most degraded coastal environment (CGR, 2017). Therefore, a future evolution of the ELP regarding coastal interventions, should include the regional differences highlighted in the inventory of human interventions conducted for the regions of interest.

Table 4.3. Geographical distribution of human interventions within the five ECUs of the CCC.

	ENVIRONMENTAL COASTAL UNIT				
	GUAJIRA	**VNSNSM**	**MAGDIQUE**	**SINU**	**DARIEN**
Typology Diversity	41.4%	79.3%	96.6%	72.4%	55.2%
Total Interventions	13.9%	9.8%	29.3%	30.8%	16.2%
Overall TEI	10.5%	10.7%	33.5%	29.7%	15.5%

Another implication for coastal policies is observed regarding how the impact of a type of intervention can be magnified in proportion to its frequency of occurrence. The relevance of the TEI, rather than the UEI, suggests that each coastal region may estimate its territorial carrying capacity for the more frequent coastal interventions. This estimation was already suggested for marine and coastal environments in the EIA regulatory frameworks of Spain and Italy (Pereira et al., 2018). Although methods for estimating the territorial carrying capacity in the EIA context exist (Loro et al., 2014), these methods have yet to discriminate the type of environments being disturbed by human interventions and their ecosystem processes. In the Colombian case, this situation becomes highly critical, where two national policies are related to coastal management but none mention the concept of territorial carrying capacity.

A third policy implication stems from countries with traditional coastal regulation, such as Cuba and Italy. This suggests that environmental licensing must validate and be validated by territorial planning instruments, such as land use, coastal management, watershed management, and marine spatial plans (Botero et al., 2016; Pereira et al., 2018). Therefore, the ELP should ensure the coherence of the proposed activity, with the territorial plans comprising the intervention area. Such validation in Colombia could be applied across three figures that involve the planning of coastal territories: the Land-Use Plan (POT in Spanish), established by Law 388 of 1997; the Watershed Ordering and Management Plan (POMCA in Spanish), established by Decree 1640 of 2012; and the Ordering and Management of Coastal Environmental Units Plan (POMIUAC in Spanish), established by Decree 1120 of 2013. However, the degree of precision and accuracy of such land and marine planning instruments is rather poor for current coastal interventions in Colombia (Botero et al., 2016). Notably, the POTs make no distinction as to whether the municipality has coastal zones (A. Ramos & Guerrero, 2010), the majority of the POMIUACs remain in their formulation stage, and the POMCAs include the coastal zone in its scope.

Consequently, the TEI estimated for each intervention's typology in each coastal region can be considered to be a useful approach for integrating coastal interventions within the land and marine planning instruments. The identification of typologies with high TEI can feature which of them require a differentiated level of administrative control, according to the results of each coastal zone. Given the frequency and spatial distribution of the types of interventions representing high values in the overall TEI, their regulation can be integrated into territorial planning instruments and other administrative procedures (e.g., concessions or environmental management plans) instead of following individual ELPs. Additionally, medium TEI values would represent restriction levels that territorial authorities would have to enforce, considering the coastal susceptibility to the effect of the intervention typology. A periodic diagnosis of the overall environmental impact in a given country through an exhaustive inventory of interventions, such as in this research, would provide technical criteria to formulate and update the territorial planning instruments.

In summary, this approach suggests that territorial planning should evolve with the concurrent reality of the types of interventions regulating the overall environmental impact. The typology CYP in Colombia is an example of how highly impactful interventions should transcend into a broader territorial approach rather than being limited to the microlocal scale of the environmental licensing. This typology has the highest TEI value because of the uncontrolled emplacement of rigid structures to protect localized areas from littoral erosion, without considering the side effects on down drift coasts (Pranzini et al., 2015). Although shore protection works are embedded in the Colombian scheme of ELP, hard works to counteract littoral erosion should have complementary control through restrictions and guidelines delineated in a regional plan for coastal management instead. The Italian region of Liguria is a satisfactory example: the protection plan of the marine and coastal environment (similar to the POMUACs of Colombia) segments the shoreline into physiographic units of different orders (i.e., units, intermediate units and cells) to validate the feasibility of coastal protection works (Liguria, 2011). In addition, this plan is articulated in the ELP because the policy is a binding reference to narrow the scope of the effects attributed to this type of intervention and prioritize the elements of technical judgment (Pereira et al., 2018).

Finally, the literature has indicated that the susceptibility of the natural system to damages or threats from the construction, operation, and dismantling of human interventions must be assessed within the EIA (Luers, 2005; Toro et al., 2012). Therefore, an improvement to the ELP of coastal interventions should rely on recognizing the natural susceptibility of littoral environments to the effect of human activities. In other words, the improvement implies supporting EIA technical guidelines according to the type of environment to be perturbed, which is highly diverse in tropical countries (e.g., coasts, desserts, dry forests, valleys, piedmonts, mountains, plateaus, continental wetlands, wet jungles, prairie, among others). Therefore, any proposal of coastal policies or regulations in tropical developing countries, such as Colombia, should recognize the broad diversity of its environments and interventions and their subnational economic, social, and natural trends.

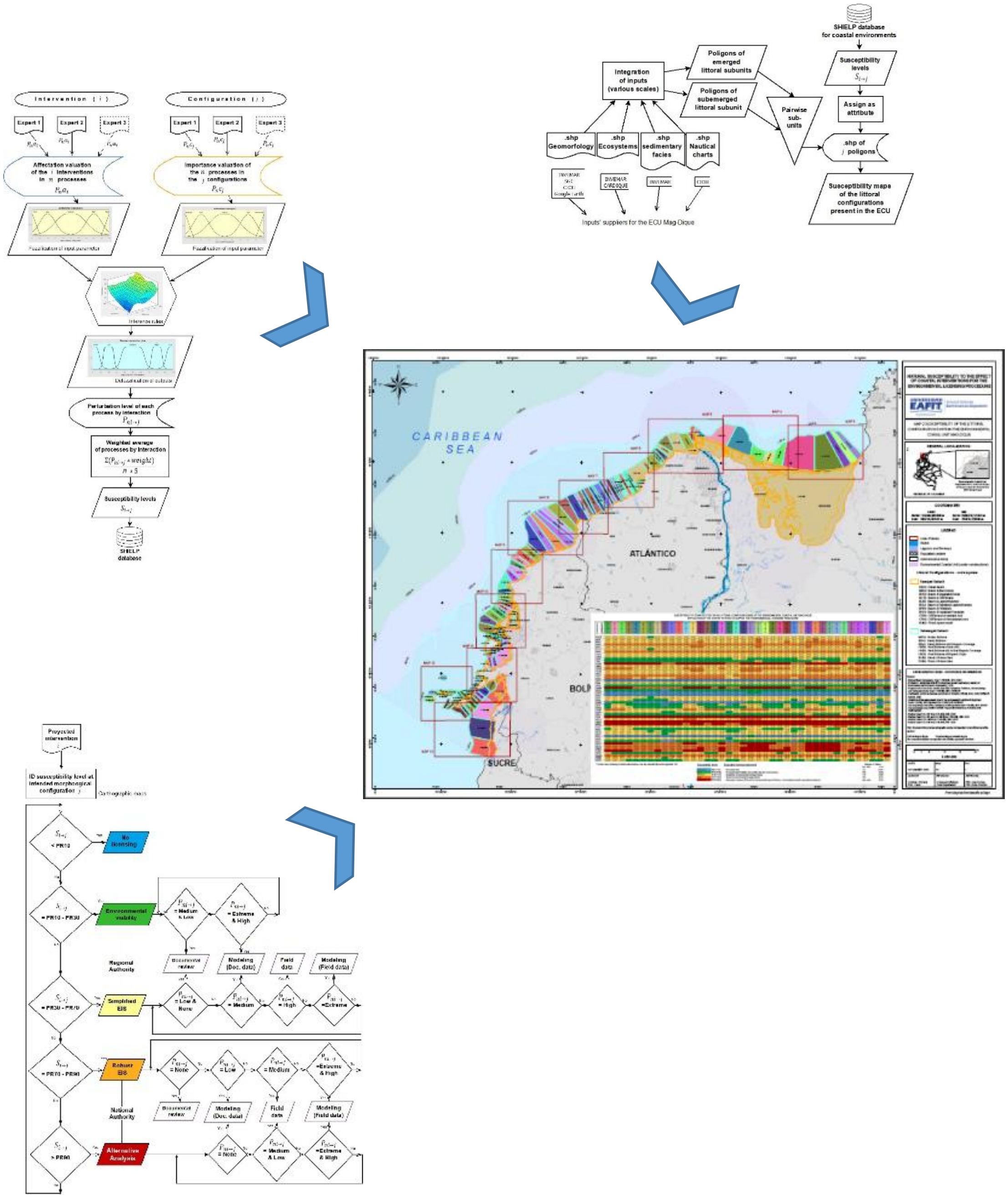
4.5. Conclusions

Tropical countries have very diverse and complex coastal environments, that must be carefully protected from human interventions. The review of the EIA regulatory framework in Colombia, a tropical developing country, confirms a loss of restrictiveness that allowed the implementation of several interventions without conducting impact assessments during the governments that ruled from 2002 to 2014. The ELP in Colombia only covers just less than half of the coastal interventions, leaving 6 of the 10 most frequent and impactful types of interventions inventoried without guidelines (AHB, AHM, AHU, EDN, UAG, GRA and EDF). Additionally, the EIA of coastal interventions is sorely dictated by the type of intervention regulated, leaving aside the consistency of this evaluation with the natural processes influencing the coast. Furthermore, the geographic data model and the structure of the ToR fragment the environment into components and fail to refer to the holistic principle of nature. Therefore, ToR should be accompanied by maps of susceptibility to the effect of human interventions, supported in a conceptual model that crosses the natural processes influencing the types of environment with the most frequent and probable interventions therein.

Coastal environmental policies and regulations should widen their scopes and integrate all types of interventions. The ELP instruments, such as the EIA, ToR, and environmental diagnosis of alternatives, should be complemented with environmental planning instruments. This study highlighted that territorial carrying capacity and coastal and marine planning are core instruments to control the environmental impact of several small but frequent coastal interventions from a precautionary approach. Accordingly, the environmental coastal regulation, at least in Colombia, should move from the perspective of single and insolated intervention or sector to multiple, simultaneous, and diverse interventions at a regional scale. This novel approach requires an assessment of the natural susceptibility of littoral environments to the effect of all potential human activities. This proposal also implies that tropical developing countries may benefit from adjusting its ELP to effectively include such an environmental susceptibility assessment as a tool within the coastal and marine policy cycle.

CHAPTER V

Susceptibility to the effect of human interventions: Design and demonstration of a conceptual and methodological model to improve the environmental licensing of coastal interventions



5.1. Introduction

In most territories, decision making over the human-induced effects on natural settings relies on an Environmental Licensing Procedure (ELP), which comprise a set of administrative protocols that depend on the outcome of a technical Environmental Impact Assessment (EIA). Although the EIA attempt to foresee the physical, biotic and social susceptibility of natural systems to projects or activities (Toro et al., 2012), diverse interpretation of the environmental regulatory guidelines lead to subjectivity issues, not to mention ethical issues associated to corruption (Bragagnolo et al., 2017; Castley et al., 2003; Enríquez-de-Salamanca, 2018; Aled Williams & Dupuy, 2017). In addition, the technical criteria framing these assessments hardly consider the particularities of the interaction man-environment that discriminate the different spheres of susceptibility (Pereira et al., 2018; Zhang et al., 2013). Therefore, it is pertinent to focus the susceptibility analysis of a location according to the effects of human interventions through a conceptual and methodological reference to reduce subjectivity in the environmental control of anthropogenic impacts.

Majority of publications link the susceptibility term with the vulnerability concept in a context of risk assessment (Luers, 2005; Paul, 2013); except for Rangel-Buitrago and Anfuso (2015b), who integrates the susceptibility of distinctive landforms with driving forces inducing erosion to determine a hazard instead of vulnerability. In a general context, the susceptibility is the tendency of a system to be affected or experience damage (Emrich & Cutter, 2011; Paul, 2013). A similar approach defines susceptibility as the degree of fragility or propensity of an element, object or terrain to present changes in its internal structure or developing a potentially harmful phenomenon (IDEAM, 2001). Turning this approach into the purposes of the impact assessment, the ***susceptibility*** can be defined as **the *predisposition of an environmental unit to experience changes or affectation due to the introduction of a human intervention***. In this concept, the environmental unit is understood as any socio-natural system subject to management through an environmental license.

On the other hand, the susceptibility is directly related to the resilience of the environmental factors and the intrinsic and independent character of the event triggering the changes in the system (IDEAM, 2001; Toro et al., 2012). Even though environmental geomorphology often analyzes physical susceptibility or vulnerability with respect to natural hazards (e.g. sea level rise, mass movements, flooding, erosion), the anthropogenic changes induced on the natural system are often disregarded at large territorial scales (Fitton et al., 2016; Gómez et al., 2017; Goodhue et al., 2012; Mahapatra et al., 2013; Mcfadden, 2010; Rangel-Buitrago & Anfuso, 2015; Satta et al., 2016; Torresan et al., 2012). This is due in part to the fact that the characteristics of the human affectations vary distinctively from one intervention to another and from one landform to another. Therefore, an improvement in the assessment and control of environmental impacts requires a new conceptual model about **Susceptibility to the effect of Human Interventions for Environmental Licensing Purposes**

(**SHIELP**). The susceptibility approach here proposed addresses to the particularities of the human-environment interaction through one intersecting geomorphological element: the natural processes influencing landform evolution at distinctive kinds of environments.

Therefore, this document has two purposes: 1) Consolidate a methodological approach of SHIELP, defining alongside the parameters for the coastal zone as a type of environment, and 2) Demonstrate the operation of the SHIELP model in an Environmental Coastal Unit (ECU) of the Colombian Caribbean.

5.1.1. Conceptual scheme of susceptibility to the effect of human interventions

Proposals for evaluating the effect of human interventions on the coastal geomorphology are rather scarce in the wider framework of environmental studies. This approach is mostly addressed to the analysis of specific cases of particular locations or projects (Dewidar & Frihy, 2007; Frihy, 2001; Fuentes-Bargues, 2014; Kämpf & Clarke, 2013; Rivillas-Ospina et al., 2017). Furthermore, EIA regulations are not usually explicit about considerations on geomorphological processes, but generic geomorphological characteristics are implicit in the reference to other environmental components (Botero, Manjarrez, Marquez, & Pereira, 2018; Rivas et al., 1997). Geomorphological characteristics tend to be considered by non-specialist and the general public as permanent features of the landscape, without realizing that such configurations obey to a dynamic equilibrium within the geomorphological processes involved (Cendrero et al., 2001).

The role of geomorphology on the EIA differentiates landforms and processes in the relationship man/environment as passive assets and active hazards, respectively (Cendrero et al., 2001; Panizza, 1996b). However, the geomorphological processes end up being the backbone of this relationship, regardless of their direction and their role, because processes are also responsible for configuring a landform (Panizza, 1996b). Following this reasoning, the proposed approach of susceptibility to the effect of human interventions seeks to articulate both geomorphological elements (landforms and processes) to set technical criteria for early stages of the ELP. This conceptual approach considers the disturbance of the natural processes by a human intervention, and the relevance such processes have on maintaining the morphological configuration of a landform in its dynamic equilibrium (Cendrero et al., 2001). Therefore, the resultant susceptibility describes the predisposition of a given landform to experience a disturbed evolution due to the human perturbation of the geomorphological processes configuring it.

In detail, Figure 5.1 represents the following conceptual scheme: the natural geomorphological evolution of a landform (j) is determined by the operation of a set of processes (P_n), each having a differentiated level of importance in achieving the current geomorphological configuration $(P_n c_j)$. When a human intervention (i) is introduced in a natural setting, it may trigger distinctive modifications or affectations to each of the processes configuring the landform ($P_n a_i$). Such changes can include the acceleration, deceleration, regression or blockage of the transferrin mechanism of matter and energy described by each process. The resultant geomorphological evolution, from the interaction of a human intervention over a geomorphological configuration ($i \rightarrow j$), is represented by n perturbation levels, one for each process ($P_{ni\rightarrow j}$). The integration of these perturbation levels into a single value is thus defined as the susceptibility to the effect of human interventions in a given interaction ($S_{i\rightarrow j}$).

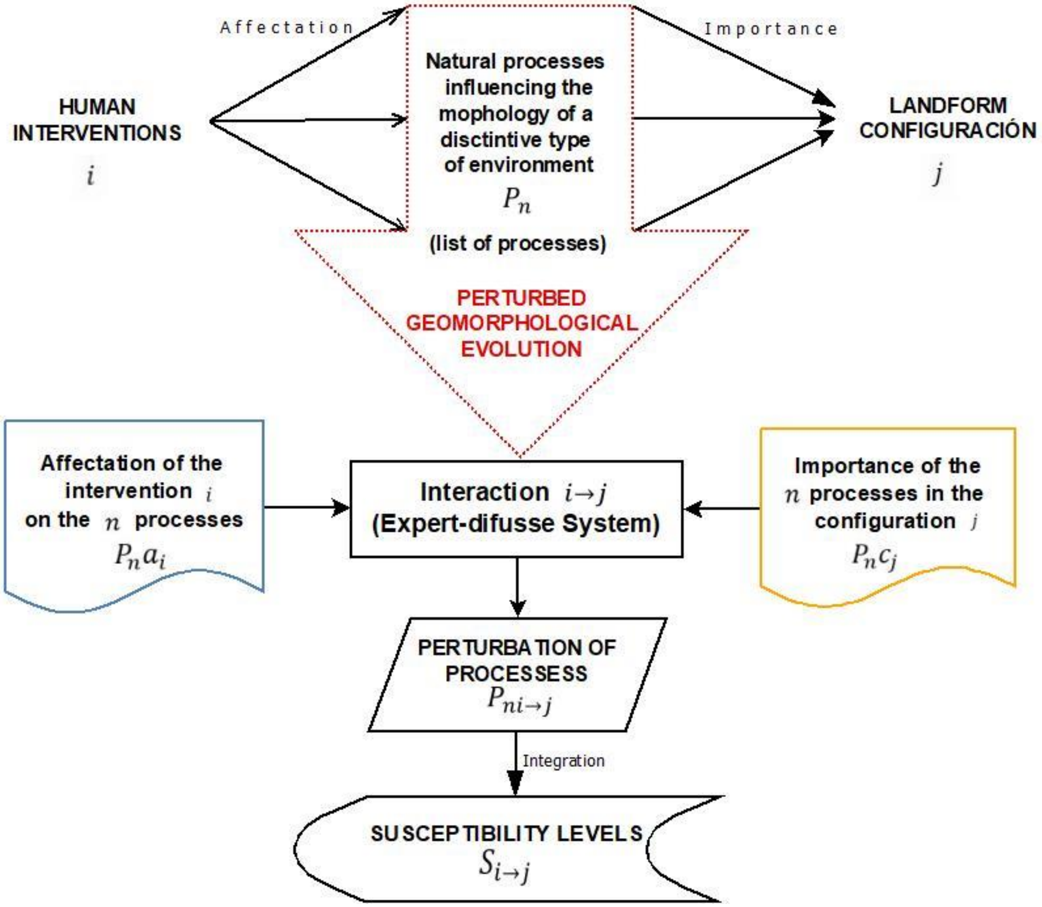


Figure 5.1. Conceptual diagram of susceptibility to the effect of human intervention for environmental licensing purposes (SHIELP)

In the main, the SHIELP model represents the disturbed evolution of a landform due to a human intervention by estimating differentiated levels of perturbation within the geomorphological processes configuring a characteristic landform. Given the limited understanding of the dynamic qualities in geomorphological processes, the predictions about a process' evolution when certain change is induced are imprecise (Rivas et al., 1997). Consequently, the proposed estimation of the susceptibility supports on expert knowledge about two parameters: processes' affectation by the human intervention and processes' importance for the landform configuration.

Additionally, the proposed computation strategy to evaluate the processes' perturbation relies on the fuzzy set theory which has proven useful when dealing with a system based on expert knowledge (Besné et al., 2018). The fuzzy logic can integrate human expertise into assessments because it generalizes the classic bivalent logic through multiple degrees of membership valued in intervals rather than binary sets, which is closer to the human reasoning (Canavese, Ortega, & Queirós, 2014). Therefore, the proposed SHIELP model articulates an expert-diffuse system because it relies on expert knowledge about geomorphological processes and fuzzy logic as a computation strategy.

5.1.2. The SHIELP application for coastal environments

Even though the boundaries of the coastal zone may comprise extensive areas due to political, historical or administrative issues, the geomorphological criteria may narrow them down into dimensions better addressed for the management goals in the ecosystem services approach (Downs & Booth, 2011). In this sense, the littoral area can be considered as the most fragile area within the coastal environment because of the dynamic equilibrium involved in the land-sea interface (Bird, 2008; Kelletat, 1995). Moreover, the morphological manifestation of this interface zone often behaves as an indicator of environmental and integrated coastal management issues.

In other words, the problems of shoreline erosion, coastal pollution, urban marine floorings and terrain salinization, among others, evidence underlying disruptions of the natural flow of matter and energy in the coastal system (Alcántara et al., 2014; Bush et al., 2001; Correa et al., 2005; Dewidar & Frihy, 2007). At the scale of a project, work or human activity, the littoral configurations may represent a geomorphological criterion to scope the reach of the environmental management of coastal interventions through the licensing procedure. The distinction of littoral landforms for the SHIELP approach on coastal environments may approximate to degrees of resistance or stability, which are further differentiated by the processes configuring them.

5.2. Methods

The two purposes of this chapter were addressed through the 10 steps depicted in Figure 5.2. For consolidating the SHIELP model for coastal environments, the parameters were defined, generated and computed through the first seven steps. The following three steps are articulated to illustrate in a study area how the SHIELP model would operate. Such demonstration was structured by adapting available data into the model parameters, filtering the susceptibility variables and interpreting the output values toward the licensing procedure. The activities completed in the four phases of the research methodology are detailed in the following sections.

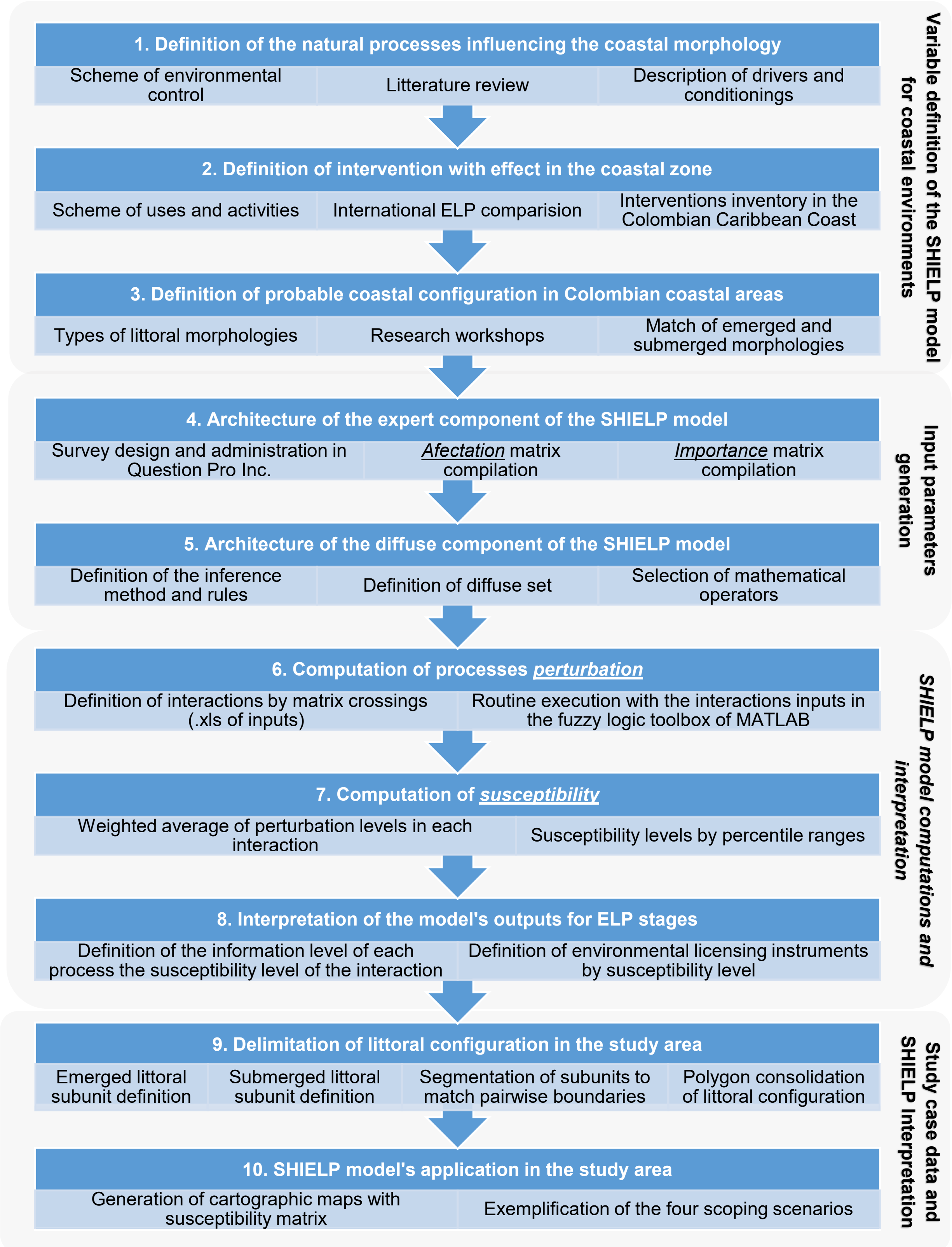


Figure 5.2. Steps of the research's methodology

5.2.1. Parameter definition of the SHIELP model for coastal environments (see Figure 5.2.)

Step 1. Processes

Due to the novelty of the research approach, it was necessary to ***conceptualize the natural processes influencing the coastal morphology***. The list of coastal processes defined for the SHIELP approach was inspired by a document about environmental generalities and regulations for the coastal zone used by the Ministry of the environment of Cuba (Brito, 2012). This document was considered an appropriate referent because it is used for the environmental control of coastal zones, which is in practice the same purpose of the susceptibility assessment to the effect of human interventions. Additionally, a literature review highlighted the main coastal processes relevant to Colombian coasts and their distribution among the Geological, Geochemical, Climatic, Hydrodynamic, Eolic and Biogenic categories. The description of the processes, its driving forces or origin and conditionings where based on the contributions of Kelletat (1995), Masselink et al. (2011), Morton and Pieper (1977), Pranzini (2004), Prothero and Schwab (2013), and Bird (2008).

Step 2. Human interventions

The triggering events in the SHIELP approach refer to the human interventions with an actual and potential effect on the coastal zone. The ***definition of*** *such* ***interventions*** was based on the scheme of uses and activities in the coastal zone, adapted to the conditions of tropical countries (Barragan, 2003; Botero et al., 2014; Silva et al., 2014). The list of interventions was complemented by the comparison of the projects, works and activities under environmental licensing within the four countries of different development status analyzed in Chapter II, Colombia included (Pereira et al., 2018). In order to stress the pertinence of the SHIELP model to the reality of Colombian coastal zones', the final list was perfected from the inventory of human interventions reported in Chapter III.

Step 3. Littoral configurations

As the subject of the SHIELP model in this application, the coastal zone needs to be segmented according to distinctive types of littoral morphologies. The ***definition of the probable littoral configurations in Colombia*** was based on the revision of the main coastal classifications worldwide used (Fairbridge, 2004; Finkl, 2004) and the Colombian standards of geomorphological surveys in coastal zones (Carvajal, 2012; DIMAR-CIOH, 2013; J. Gomez, Carvajal, & Otero, 2012). Specific workshops were held with the geosciences program of the national research institute of marine and coastal areas INVEMAR (in Spanish: Instituto de Investigaciones Marinas y Costeras José Benito Vives de Andrei), in order to identify the types of littoral morphologies observed in Colombian coasts, both emerged and submerged. The distribution and organization of the selected emerged morphologies was inspired in the coastal typologies of the Cuban legal system and its improvement proposals (GORC, 2000; Milanes, 2018; Milanes, Pereira, & Botero, 2019). The final littoral configurations were the result of matching the selected emerged composition of morphologies with the selected submerged ones.

5.2.2. The architecture of the SHIELP expert –diffuse system: inputs generation

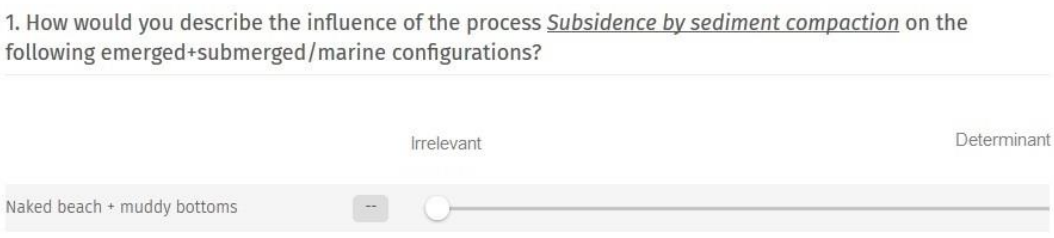
As previously stated, the SHIELP model results from combining an expert system for defining incoming parameters with a computation strategy based on fuzzy sets. Within this stage of the SHIELP methodological approach, several software and applications were used as tools for data collection, compiling and computation, including Question Pro Inc., Microsoft EXCEL® and MATLAB®.

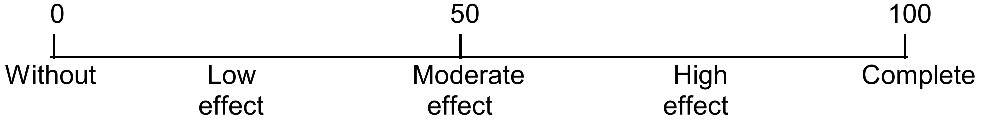
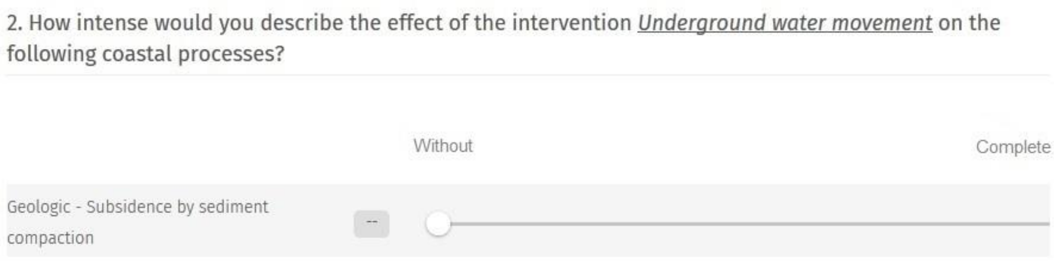
Step 4. The expert knowledge component of the SHIELP model for coastal environments

The **architecture of the component that involves expert knowledge** creates data about the input variables to be computed by fuzzy logic. This required the design of the surveys to be filled by the group of experts in coastal processes involved in the research workshops. A total of ten experts in geosciences took the surveys, including the following fields of expertise: geology, geography, oceanography, marine geophysics, biology, environmental geochemistry, physics engineering, coastal dynamics, and environmental engineering.

Two types of questionnaires were designed through the online service Question Pro Inc., one for rating processes' importance in the littoral configurations (type 1) and the other for processes' affectation due to the human interventions (type 2). A sample of the questionnaire introduction and question format is presented in Table 5.1.

Table 5.1. Elements of the two types questionnaires designed in the online survey service

IMPORTANCE QUESTIONNAIRE (Type 1)	Introduction	Please consider the following scheme to qualify the influence level of the coastal processes on the geomorphological configurations. 0 — 50 — 100 Irrelevant · Low influence · Moderate influence · High influence · Determinant Answer this questionnaire by sliding the bar from zero (0) to one hundred (100) in each question.
	Question sample	 1. How would you describe the influence of the process <u>Subsidence by sediment compaction</u> on the following emerged+submerged/marine configurations?

AFFECTATION QUESTIONNAIRE (Type 2)		
	Introduction	Please consider the following scheme to qualify the effect of each human intervention on the natural processes influencing the coastal morphology.  Answer this questionnaire by sliding the bar from zero (0) to one hundred (100) in each question.
	Question sample	 2. How intense would you describe the effect of the intervention *Underground water movement* on the following coastal processes? Geologic - Subsidence by sediment compaction

The style of question used was the numeric slider, from the category of graphical ratings. In each question, the expert was asked to qualify the corresponding effect/influence of one variable written in the enouncement into another set of variables placed in the sliding bars. Questionnaire type 1 contained 21 enouncements, corresponding to the coastal processes, regarding 87 sliding bars of littoral configurations for each enouncement. Questionnaire type 2 contained 52 enouncements, corresponding to the types of interventions, regarding 21 sliding bars of coastal processes for each enouncement.

While the request for rating the relevance of a process in a coastal configuration was rather intuitive for experts, the qualification of the interventions' effect requires additional context. Within the indications given to the experts during the survey administration, it was included a scale of diffuse categories with examples of attributes that could be considered for the assessment (see Table 5.2). Additional indications offered in the survey administration session included:

- The effect of an intervention must have been qualified regardless of the nature of the perturbation: either the intervention accelerates, slowdowns or stops a process.

- All processes were assumed to take place in the interaction considered, which means to consider worst-case scenarios of interventions on critical locations.

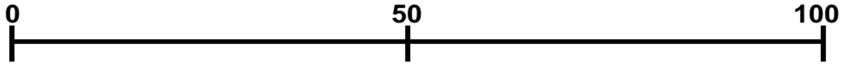
- Processes inertia (resistance to perturbation and delay in its manifestation) was considered as an affectation attribute similar to the derivation of effects.

- Perturbation area comprises the coastal zone boundaries defined by Decree 1120 of 2013: 2 kilometers inland from the shoreline, transition vegetation or lagoon flooding mark, and the 200 meters isobaths in the sea.

- Interventions in the category “Drainage basin alterations” refer as to the direct low coastal micro-basin.

The surveys were administrated within the months of June and September of 2018, ensuring at least two expert assessments for each enouncement. Once the surveys were completed, the data were obtained from the automatically generated reports of the online survey service that compute the mean value of the answers registered. Raw data reports were downloaded directly from the service into spreadsheets of Microsoft EXCEL®. This ease compatibility with the input files further required for the fuzzy logic computations in MATLAB®. Resulting data were compiled in two matrices, one crossing each process with each littoral configuration (IMPORTANCE matrix) and the other crossing each process with each human intervention (AFFECTATION matrix).

Table 5.2. Considerations suggested for the experts during the administration of the questionnaire type 2



Example Attributes	**Without**	**Low effect**	**Medium effect**	**High effect**	**Complete**
Moment of the generation of the effect	Absent	Construction	Construction AND/OR operation	Construction AND operation	Construction AND operation
Scope of the effect (origin and reach)	Absent	Inside OR outside the coastal zone	Inside OR outside the coastal zone	On-site	On-site (e.g. burial)
Derivation of effects	Absent	Indirect	Direct OR indirect	Direct OR indirect	Direct AND indirect
Example of “Littoral mass movements”	Fishing	-	Carving of crop drains/golf courses	-	Quarrying/ dredging

Step 5. Diffuse component of the SHIELP model for coastal environments

The **component that involves a fuzzy logic computation** translates the experts’ knowledge captured by the surveys into an integrated description of processes’ perturbation in a singular interaction (intervention vs configuration). The fuzzy logic toolbox in MATLAB was used for setting the parameters of the fussy system algorithm (MATLAB 9.2., 2017). Initially, the Mamdani inference method was selected because it is well suited for human inputs, which is the knowledge base of the system. Additionally, the linguistic rules defined for the fuzzy system have the form “IF X AND Y

THEN Z" where X, Y, and Z represent fuzzy sets. In this sense, the rules have an approach such as "IF [the condition of Process Importance] AND [the condition of Process Affectation] THEN [the condition of Process Perturbation]".

A total of 25 rules were defined (see Table 5.3), based on the following conditions:

- When the levels of importance and affectation are equal or are one level of difference, the resultant perturbation level is equal to the affectation.

- When there are two (2) levels of difference between affectation and importance, the perturbation is one (1) level of difference from the affectation.

- When there are three (3) levels of difference between affectation and importance, the perturbation is two (2) levels of difference from the affectation.

- When there are four (4) levels of difference between affectation and importance, the perturbation is three (3) levels of difference from the affectation.

- Regardless, the perturbation level can never be lowered more than one level from the affectation.

Table 5.3. Inference rules of the fuzzy Logic system defined for coastal environments.

Process Importance	Process Affectation				
	Without	**Low**	**Medium**	**High**	**Complete**
Irrelevant	None Perturbation	Low Perturbation	Low Perturbation	Medium Perturbation	High Perturbation
Low	None Perturbation	Low Perturbation	Medium Perturbation	Medium Perturbation	High Perturbation
Medium	Low Perturbation	Low Perturbation	Medium Perturbation	High Perturbation	High Perturbation
High	Medium Perturbation	Medium Perturbation	Medium Perturbation	High Perturbation	Extreme Perturbation
Determinant	High Perturbation	High Perturbation	High Perturbation	High Perturbation	Extreme Perturbation

Next, the fuzzy sets are represented by the use of linguistic variables and membership functions, which describe the domain of incoming and output parameters. The membership functions for the two incoming parameters are a combination of generalized and sigmoidally-shaped bells functions, with the five fuzzy sets defined in the rules (Figure 5.3). The amplitude defined for this fuzzy sets sought the closest representation of the instructions given to the experts in the surveys with the sliding bar. On the other hand, the membership functions of the same five diffuse sets of the output are represented by generalized bells, with a reduced distance between the crossover points for a more discrete output.

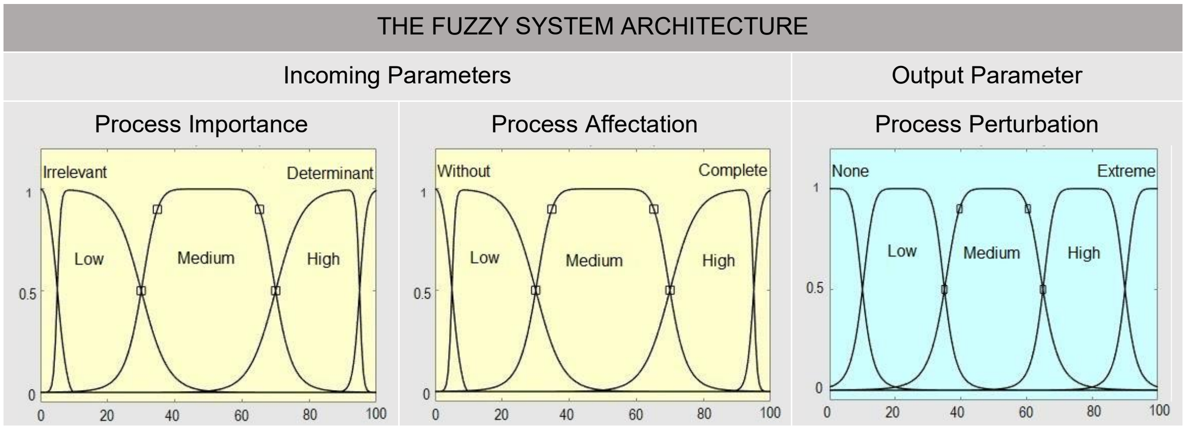


Figure 5.3. Fuzzy System Architecture to evaluate process perturbation in a given interaction (human intervention vs morphological configuration)

At last, it was defined as a minimum operator for the rules and the implication aggregation and a cumulative sum operator for union aggregation. For the concluding phase, the Largest-of-Maximum-of-the-Area technique ("lom") was applied for the numeric score generation. The surface obtained by mapping the fuzzy system is depicted in Figure 5.4, which demonstrate how perturbation values are conditioned by high values of affectation and grow with increased values of importance. Both elements of membership functions and operation parameters were set to ensure the inclusion of the extreme values and represent gradual transitions within the resulting perturbation values.

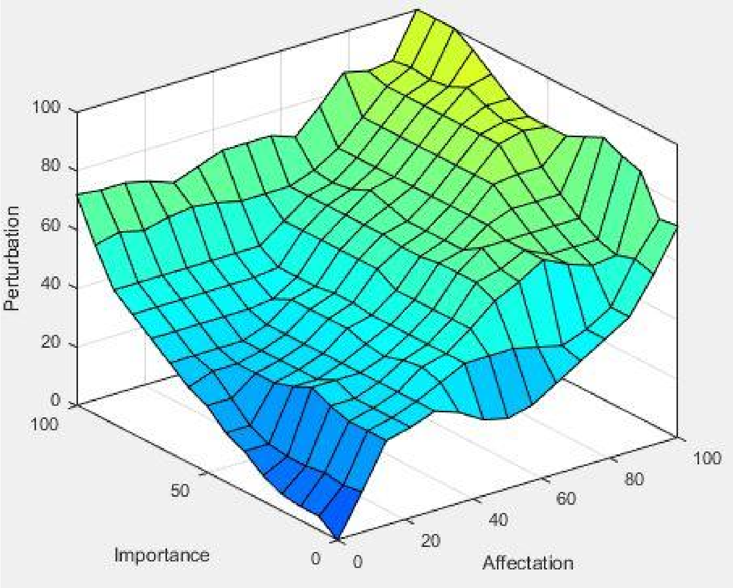


Figure 5.4. Fuzzy incoming parameters (Importance and Affectation) and resulting output (Perturbation)

5.2.3. SHIELP model computations

Sep 6. Processes perturbation

The perturbed evolution of a given landform due to an anthropic activity obeys to the interception between the human-induced affectation on each process and the respective processes' relevance on the landform configuration. Therefore, **the computation of processes perturbation** in each interaction required the preparation of the data to introduce them as incoming parameters into the fuzzy system. To that end, the number of interactions to be computed were defined by crossing each human intervention with each littoral configuration, both variables set for the SHIELP model for coastal environments. Since the incoming parameters of the fuzzy system correspond to the affectation and importance qualifications of each process in a given interaction, the inputs were organized into spreadsheets of two rows, one for each parameter in the strict order of the list of processes. The third row was left for the computation software to write the fuzzy system outputs. To this end, a routine file (.m) was created in MATLAB, to program the commands to be used for running the fuzzy system in every interaction. Table 5.4 summarizes the commands written in the routine.

Table 5.4. List of commands used in the MATLAB routine file to run the application of the SHIELP model of coastal environments in the study case area.

Command	Performance
xlsread	Call and read the spreadsheet containing the input values of affectation and the importance of the processes in the interaction (intervention vs configuration)
readfis	Call and execute the file containing the settings of the fuzzy system (inference method, membership functions, inference rules, and aggregation operators)
for end	Open and closes the computation cycle according to the number of rows in the spreadsheet input files
xlswrite	Writes the fuzzy system output in the final column of the spreadsheet files

Step 7. Susceptibility at every interaction (intervention i on the configuration j)

The **final computation** in the SHIELP model for coastal environments **is the susceptibility at each interaction**. The operator used for this computation is a weighted average of the perturbation values of the n processes in every interaction. The Table 5.5 presents the weight assigned to each perturbation level and the mathematical expression to integrate the n perturbation values into a single susceptibility number by interaction. Up to this point, the application of the SHIELP expert-diffuse system to the parameters of coastal environments have turned into a big database, ready to be construed in the study areas once their littoral configurations are delimited.

Table 5.5. Weights of the perturbation levels and the equation to integrate them into a susceptibility value.

Range value	Perturbation Level	*weight*	Susceptibility
0 – 10	None	1	$\frac{\sum(\boldsymbol{P_{ni\to j}} * \boldsymbol{weight})}{\boldsymbol{n} * \boldsymbol{5}}$ ∴ $\boldsymbol{P_{ni\to j}}$ = Perturbation level of the $\boldsymbol{n}$ process in the interaction of the intervention $\boldsymbol{i}$ on the littoral configuration $\boldsymbol{j}$.
10.01 – 35	Low	2	
35.01 – 65	Medium	3	
65.01 – 90	High	4	
90.01 – 100	Extreme	5	

Steps 8. Interpretation of the SHIELP model´s outputs

The susceptibility values of all the interactions were categorized into five categories (very low, low, medium, high and very high), according to percentile ranges. For the interpretation of this output, four instruments of environmental licensing were proposed to pair the susceptibility levels, leaving the lowest one as a threshold for cases where a full licensing procedure is not encouraged. This proposal of parameters to construe the SHIELP model's results would emulate technical criteria for improving the Colombian ELP at the early stages of screening and scoping.

In this sense, the screening refers to the type of instrument (or preliminary decision) an environmental authority could release to a licensing request according to the susceptibility class its variables fit in. On the other hand, the scoping defines the information levels required from each process for the impact assessment through the baseline definition, which correlates with the four types of environmental licensing instruments proposed. The results on Section 5.3.8 include examples of the four scoping scenarios, as well as a decision diagram through which environmental authorities can use the SHIELP model.

5.2.4. Study case

The area selected for the SHIELP model demonstration is one of the five Environmental Management Units (ECU) defined for the Colombian continental Caribbean by the environmental national policy for the sustainable development of oceanic areas and coastal and insular zones (MMA, 2000). Within these, the unit "Magdalena River - Canal del Dique complex - Ciénaga Grande de Santa Marta lagoon system" (Mag-Dique) presents the higher availability of geographical information from official sources. Therefore, it was selected as the study case area.

The legal recognition of these environmental units went through Decree 1120 of 2013, which defines the alongshore limits (Cordoba river mouth and Punta Comisario) and provides indications of the inland and offshore reach. In lieu of precise boundaries, only approximated limits of the ECU Mag-Dique are available at official environmental information repositories under the following warning: "delimitation still under construction by the Ministry of Environment". Figure 5.5 represents the geographical setting of the study area and its main morphological features.

In the main, the approximated limits for the ECU Mag-Dique comprises nearly 87,000 square kilometers, including the Tierra Bomba Island, Barú peninsula and El Rosario archipelago. The continental shoreline comprises extensive deltaic plains, represented by beach-lagoon systems, spits, and sandy barrier islands linked to extensive mangrove swamps (Figure 5.5). Two major deltaic systems are gathered in this study area: The Magdalena River and its deviation toward El Dique Channel. It also contains the grossest lagoon complex of Colombia: Ciénaga Grande de Santa Marta (CGSM). Finally, this environmental unit comprises partial territories of four administrative domains, namely the departments of Magdalena, Atlántico, Bolivar, and Sucre.

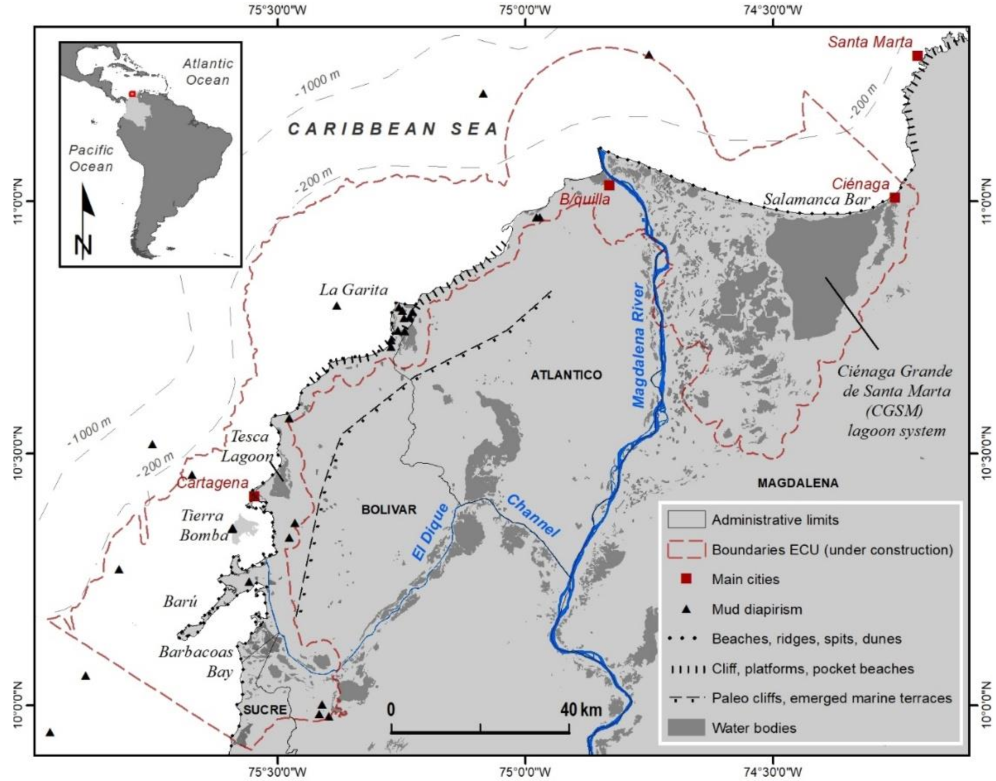


Figure 5.5. Study area: Environmental Coastal Unit "Magdalena River - Canal del Dique complex - Ciénaga Grande de Santa Marta lagoon system" (ECU Mag-Dique)

Step 9. Delimitation of littoral configuration

For demonstrating the SHIELP model operation in a study case, **data from the ECU Mag-Dique was compiled, adapted and created** with reference to the existing available information. At first, several information sources and official institutions were reached in search for geographical inputs, including INVEMAR, the national geological service SGC (in Spanish: Servicio Geológico Colombiano) and the maritime authority DIMAR (in Spanish: Dirección General Marítima) with its research institute CIOH (in Spanish: Centro de Investigaciones Oceanográficas e Hidrográficas del Caribe). Table 5.6 summarizes the data sources collected and its use in the delimitation of the littoral configurations, as defined in step 3 of Section 5.2.1.

Table 5.6. List of data used for defining the littoral configurations in the ECU Mag-Dique

Data input	Owner	Supplier	Year / Scale	File format	Use for delimitation
Preliminary delimitation of the ECU Mag-Dique (under construction)	Ministry of Environment and Sustainable development	INVEMAR	2013 / Unknown	.shp	ECU boundaries alongshore
Geomorphology and types of shoreline	(Posada et al., 2009)	INVEMAR	2007 / 1:100.000	.shp	Emerged configurations
Distribution of Sedimentary Facieses	CIOH	INVEMAR	1999 / 1:300.000	.shp	Submerged configurations
Continental, coastal and marine ecosystems of Colombia	(IDEAM, IGAC, IAvH, INVEMAR, & SINCHI, 2007)	INVEMAR	2007 / 1:500.000	.shp	Emerged configurations Submerged configurations
Guidelines of the management plan for the ECU Mag-Dique (Bolivar department)	(INVEMAR & CARDIQUE, 2014)	SIAM	2013 / 1:25.000	.shp	Emerged configurations Submerged configurations
Geomorphologic atlas of the Colombian Caribbean littoral	(DIMAR-CIOH, 2013)	CIOH	2010 / 1:50.000	Printed book	Emerged configurations
Geomorphologic map ANDEN CARIBE	(Carvajal et al., 2010)	SGC	2010 / 1:25.000	.pdf (x22)	
Nautical Chart COL 261	CIOH	CIOH	2003 / 1:25.000,	Printed book	Submerged configurations
Nautical Chart COL 407 and COL 408	CIOH	CIOH	1999 / 1:100.000		
Nautical Chart COL 409	CIOH	CIOH	2004 / 1:100.000		
Nautical Chart COL 616	CIOH	CIOH	2001 / 1:50.000		

The only sources available directly in geographical format (.shp) were accessed through INVEMAR, either by request or by the online repository of marine-environmental information they administer, called SIAM (in Spanish: Sistema de Información Ambiental Marino). Institutional policies of the other organizations made unavailable the geographical formats of their geomorphological data. In these cases, the geomorphological maps had to be scanned into images and further georeferenced in a GIS environment. An example of the mosaic compiled from this kind of sources is depicted in Figure 5.6.

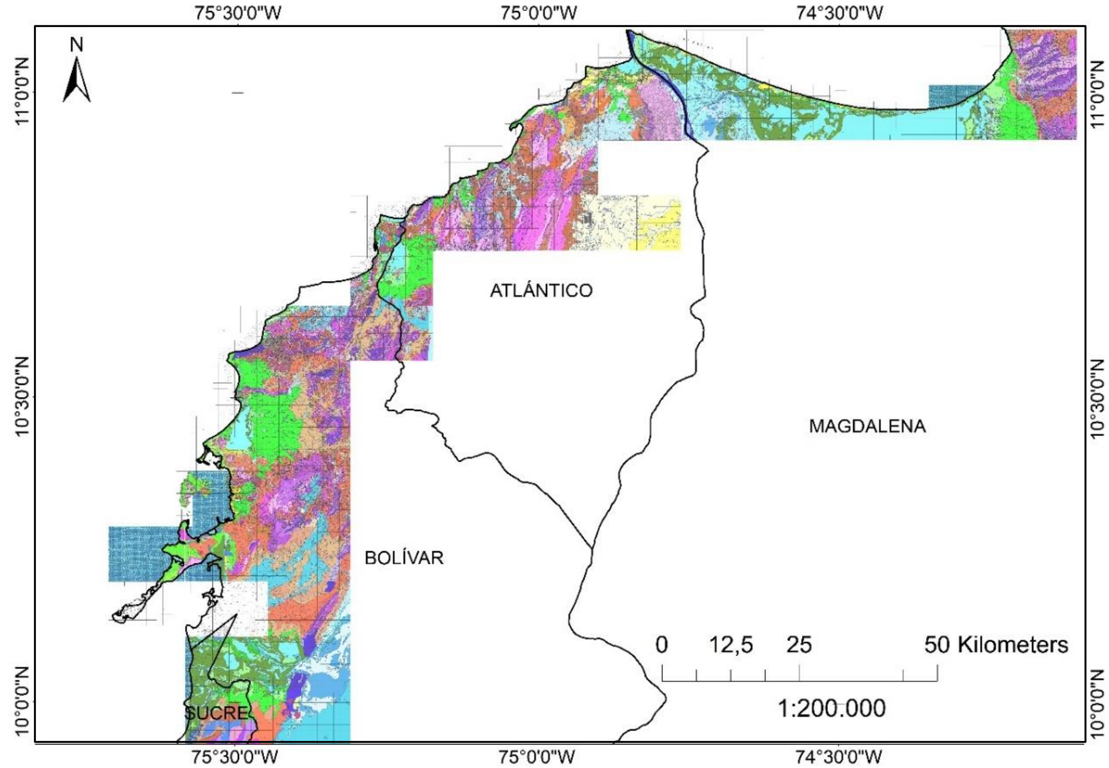


Figure 5.6. Mosaic of the 22 maps of Carvajal et al. (2010).

The software Arcgis 10.5. (2016) was used to manipulate input files for creating two new feature classes, one containing emerged morphological polygons and the other one for submerged morphologies. The emerged compositions defined in step 3 of Section 5.2.1 were discerned from the three geomorphological layers available, the two layers containing ecosystem coverages, and complementary observations of Google Earth imagery. By far, this was the richest part of the delimitation exercise in term of amount and scale variety of inputs, which allowed to manage an average working scale of 1:25.000. Conversely, the submerged configurations relied on rather scarce inputs at very gross scales, except for the partial coverage offered by INVEMAR and CARDIQUE (2014) in one of the administrative limits comprising the ECU Mag-Dique (Bolivar department). Therefore, submerged polygons were discerned from the layer of sedimentary facies, the two layers about ecosystem coverage and the nautical charts, reaching out an average working scale of 1:50.000.

Once completed the delimitation of littoral configurations into two separate feature classes, some of the polygons had to be split to match the boundaries between pairs of emerged and submerged subunits. After, each pairwise was merged into a single polygon on a different feature class, that compiled all the littoral configurations in the ECU Mag-Dique. This way, new polygons of littoral configurations are consolidated according to the scheme defined for the SHIELP model for coastal environments.

Step 10. Application of the SHIELP model in the ECU Mag-Dique

Since the universe of littoral configurations defined in the SHIELP model for coastal environments was not completely represented in the study area, the susceptibility database had to be cleaned before interpretation. This means removing from the susceptibility matrix the rows corresponding to all littoral configurations not identified in the ECU Mag-Dique, along with the perturbation levels of the processes associated with the inapplicable interactions.

Afterward, the susceptibility levels were assigned as attributes to the feature class of the littoral configurations delimited in the study case area. This file of geographical format (.shp) allowed the estimation of surface coverage by configurations and respective subunits, as well as the cartographic representations of the susceptibility to the effect of human interventions in the ECU Mag-Dique.

5.3. Results and analysis

5.3.1. The methodological approach of SHIELP

The flowchart in Figure 5.7 summarizes the final design of the SHIELP expert-diffuse system for coastal environments as a reference for eventual applications in further types of environments. The proposed evaluation of processes' perturbation for this susceptibility approach articulates two incoming parameters and one output parameter. The first parameter called the "process importance" with respect to geomorphological configurations ($P_n c_j$), is defined as "a numeric expression of the experts' rating of the relevance that a set of geomorphological processes may have on the functioning of a type of environment". The second parameter, considered the "process affectation" ($P_n a_i$), is defined as "a numeric expression of the experts' rating of the affectation level that a human intervention may have on a set of geomorphological processes". A resulting scenario that depends on both parameters has been named the "Process perturbation" ($P_{ni\to j}$), which is computed for the set of processes ruling the functioning of a type of environment. The perturbation score of such set of processes is further integrated into the susceptibility level of a particular type of intervention over a particular kind of morphological configuration ($S_{i\to j}$).

The images inserted in the flowchart of Figure 5.7 represent the three main phases of the linguistic model defined by the fuzzy set theory (Besné et al., 2018; Canavese et al., 2014; Mardani, Jusoh, & Zavadskas, 2015). Therefore, the fuzzification of inputs organizes the knowledge base captured by the expert knowledge about the role of geomorphological processes in the landform configuration for distinctive types of environments. Afterward, the inference rules describe different implication among the fuzzy sets in which the expert knowledge is translated into. Finally, the defuzzification of outputs provides well-defined results from the model, manipulating the inherent uncertainties of the human reasoning implicit in the experts' knowledge.

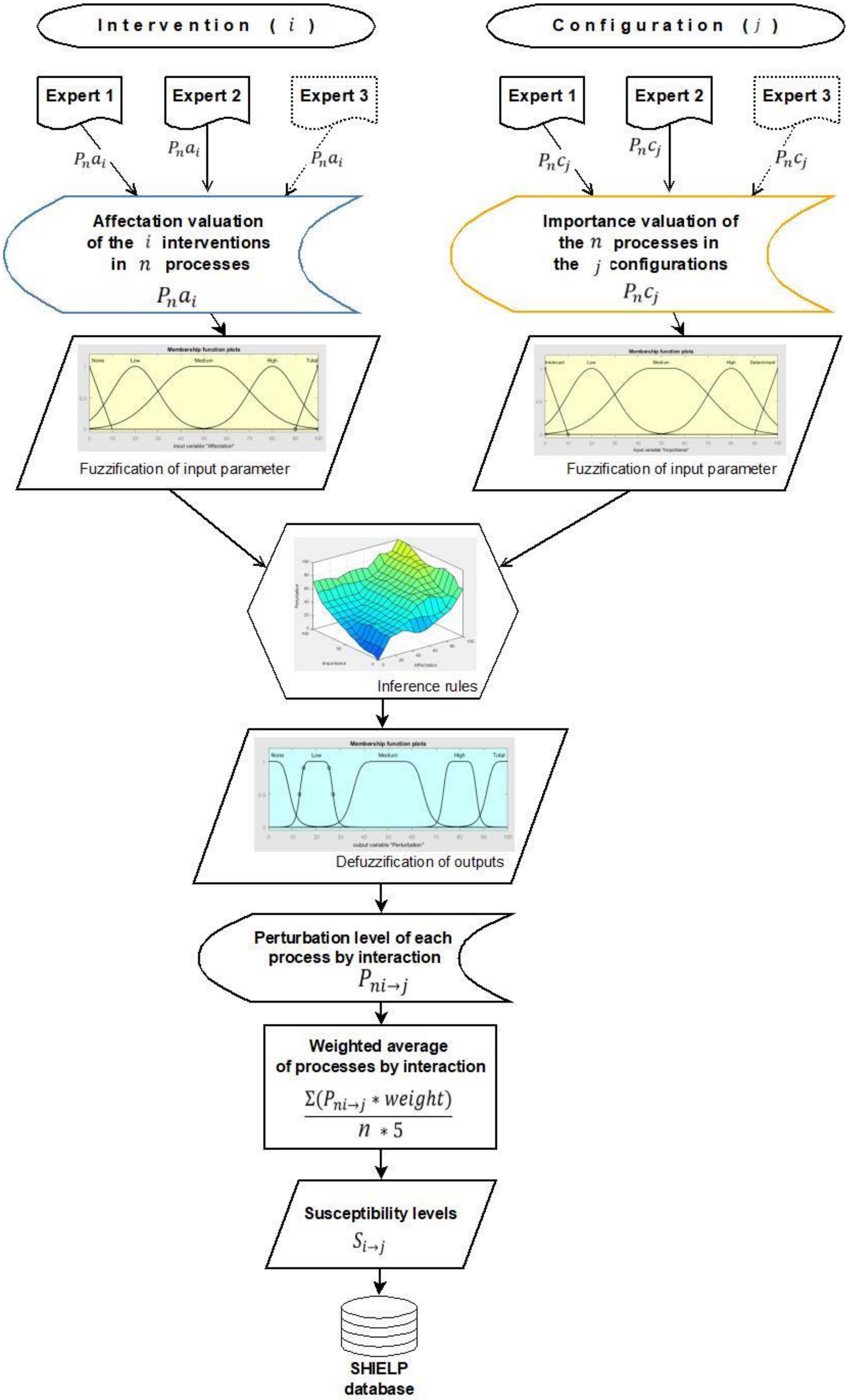


Figure 5.7. Generic flowchart of the SHIELP model architecture.

It is worth noticing that the sequence of operations described in this flowchart (Figure 5.7) can be replicated for building up susceptibility databases for distinctive types of environments. To that end, the general variables of the expert-diffuse system need to be conceptualized, namely the list of processes relevant to the type of environment, the list of probable morphological configurations and the list of human interventions worth pre-assessment.

5.3.2. Parameters of the SHIELP model for coastal environments

A total of 21 processes, distributed in six categories, were defined as the natural processes influencing the coastal morphology. Geologic processes comprise the largest amount in the list, with eight processes referring to the different factors inducing Earth movements and the geomorphological settings contributing to the origin and approach of littoral sediments (Kelletat, 1995; Pranzini, 2004). The geochemical category introduces two processes driven by the physicochemical properties of the coastal environment (Prothero & Schwab, 2013). Meanwhile, the climatic category gathers four processes mostly focused on weather patterns at large scale with local influences (Masselink et al., 2011; Morton & Pieper, 1977). There are three hydrodynamic processes describing the often combined effect of marine forces, such as wave, tides, and currents (Bird, 2008; R. Davidson-Arnott, 2010). Similarly, the two eolic processes address the effect of the wind, while the last two biogenic processes introduce the influence of living organisms in the seaside settings (Masselink et al., 2011; Prothero & Schwab, 2013). The final document that conceptualizes these 21 natural processes influencing the coastal morphology can be checked on the Appendix V-A, while Table 5.7 summarizes the categorized list.

It is worth noticing that **these list of processes** could be substantially extended; however, the processes here prioritized are the most relevant for configuring coastal environments in tropical areas, where the Colombian Caribbean and Pacific coasts are located. For example, processes of glacial character have no room in the present conceptualization because they take no place in tropical latitudes. In turn, diapirism is included to customize the list to the Colombian coastal reality, even though this phenomenon is rarely mentioned in textbooks of coastal processes. The reason for such judgment call has already been stated in previous chapters, as this particular phenomenon represents a relevant control in the coastal morphology of extensive areas in the Colombian Caribbean (from Ciénaga city to the Gulf of Urabá) (Carvajal et al., 2010).

Table 5.7. List of processes defined for the SHIELP model application on coastal environments.

Category	Process	Code
Geological	Subsidence by sediment compaction	P_1
	Vertical movements associated to diapirism	P_2
	Earth movements by neo-tectonics	P_3
	Physical weathering by structural controls	P_4
	Littoral mass movements	P_5
	Erosion in the drainage basin (sediment inputs)	P_6
	Sediment sinking by geomorphologic configuration	P_7
	Water table changes	P_8
Geochemical	Chemical formation of sediments	P_9
	Chemical weathering	P_{10}
Climatic	Eustatic sea level changes	P_{11}
	Semi-periodic sea level changes	P_{12}
	Extreme meteorological events	P_{13}
	Drainage in the basin by weather events	P_{14}
Hydrodynamic	Littoral erosion	P_{15}
	Littoral sediment transport	P_{16}
	Littoral deposition	P_{17}
Eolic	Wave generation by wind	P_{18}
	Sediment transport and deposition by wind	P_{19}
Biogenic	Biogenic sediment production	P_{20}
	Sediment fixation	P_{21}

Regarding the affectation component of the SHIELP model, **a list of 52 interventions** was established as probable projects, works or activities inducing perturbations on the natural processes of coastal environments. These human interventions were also distributed in nine categories, according to the nature of the use or activity, or the localized operation of its effects. The compiled list is summarized in Table 5.8.

There are five interventions regarding alterations of the immediate basin draining to littoral areas. Another six interventions were cataloged as edifications, within which agglomerations or singular typologies are distinguished. The category with the highest amount (11) of interventions gathers infrastructure conceived for marine navigation, as well as the commercial activities associated with this works. Even though three of these marine navigation facilities can be perceived as duplicates from three interventions in the edifications category, the particularization here inserted addresses structures directly interfering marine related processes.

Two other categories comprehend seven interventions each. Under the label of industrial and energy installations are several conventional and emerging technologies, while the category of linear infrastructure mostly gathers land related transportation facilities, either for passengers, cargo, energy or fluids. Equally distributed in four categories are the remnants of the interventions (N=16). The activities of the primary sector of the economy are mostly concentrated in two categories:

Extensive land use, including livestock, and Extractive activities. Lastly, the works of shore protection and control include the interventions that are currently included in the Colombian environmental norms, while the basic sanitation facilities refer to the works intended to fulfill the human uses of water supply and waste management.

Table 5.8. List of human interventions defined for the SHIELP model application on coastal environments.

Category	Code	Intervention	Category	Code	Intervention
Drainage basin alterations	02 UGM	Underground water movement	Extensive land use and livestock	33 UAG	Livestock, farming and golf course
	03 IDO	Irrigation districts		34 GMR	Mariculture
	04 LUC	Changes in land use (deforestation)		35 GRA	Aquaculture
	05 MOC	Modification of channels		36 TPC	Thematic parks and camping
	07 IFC	Installations in fluvial causes	Extractive activities	38 EEH	Exploration/extraction of hydrocarbons
Edifications	08 AHB	Low density settlements		39 MDS	Marine dredging
	09 AHA	High-density settlements		40 RDS	River dredging
	10 AHP	Palatial settlements	Linear infrastructure	41 CAP	Roads, double roads, bridges...
	11 AHU	Luxury settlements		42 VFE	Railways and facilities
	12 EDF	Sun, Sea and Sand Tourism		43 CAP	Tunnels
	13 MIL	Military installations on land		44 CAP	Airports and runways
Marine navigation and facilities	14 EMP	Inlet navigation channels		45 ELF	Electric lines and facilities
	15 MUP	Public Docks		46 BSP	Basic sanitation pipes
	16 AHM	Luxury settlement with pier		47 CFP	Conduction of fluids through pipelines
	17 EDM	Sun, Sea and Sand tourism with pier	Works of shore protection	48 ROP	Breakwaters and artificial reefs
	18 PUC	Deepwater ports without shelter		49 CYP	Groins
	19 PUG	Shallow water ports without shelter		50 MUR	Sea walls, walks, and ridges
	20 SPS	Sheltered ports		51 BNS	Beach nourishment
	21 FFF	Fishing	Basic sanitation facilities	52 DSP	Desalination plants
	22 INA	Naval military installations		53 SWD	Solid waste exploitation and disposal
	23 NAV	Internal Maritime Transport		54 SME	Submarine emissary
	24 MMN	Marinas		55 WTP	Wastewater treatment plants
Industrial and energy installations	26 GTP	Geothermal plants			
	27 WPP	Wind power plants			
	28 SEP	Solar energy plants			
	29 TYS	Thermoelectric plants			
	30 TSF	Transformation/storage of fossil fuel			
	31 MAN	Manufacture			
	32 GST	Geological storage			

Concerning the importance component of the SHIELP model, **it was consolidated a list of** 87 **littoral configurations**. These compositions result from the permutation of eleven emerged subunits and 8 submerged subunits (see Table 5.9). Only one match was discarded, namely river/lagoon mouth with rocky offshore features, because the workshop with experts identified it as unlikely in Colombian coasts. Overall, these littoral configurations attempt to represent the vector and cellular properties of the landscape because the intra-zonal discontinuity in the patterns of substrate distribution obeys to associations of relief and to the prevalence of biogenic coverages (Forman, 1995).

Table 5.9. Emerged and submerged morphological compositions for setting the littoral configurations.

Emerged littoral subunits		**Submerged littoral subunits**	
NBX	Naked beach	MBX	Muddy Bottoms
BBD	Beach & Bare Dunes	SBX	Sandy Bottoms
BVD	Beach & Vegetated Dunes	SBV	Sandy Bottoms with Biogenic Coverage
BCT	Beach & Cliff/Terrace	HBR	Hard Bottoms of Bare Rock
BLS	Beach & Lagoon/Swamps	HAB	Hard Bottoms with Active Biogenic Coverage
BVL	Beach & Vegetated Lagoon/Swamps	HBO	Hard Bottoms of Biogenic Origin
BFP	Beach & Floodplain	SOB	Sandy Offshore Bars
BVF	Beach & Vegetated Floodplain	ROB	Rocky Offshore Bars
CTR	Cliff/Terrace of resistant rock		
CTN	Cliff/Terrace of Non-resistant rock		
RLM	River/Lagoon mouth		

The littoral subunits in the emerged zone are the composition of couples of geomorphological features, especially for those regarding unconsolidated materials. In this sense one single feature, such as beaches, compose seven littoral emerged subunits with complementary littoral features that may represent cushioning systems (e.g. lagoons, dunes, and floodplains).

On the other hand, both emerged and submerged littoral subunits can be seen as duplicating geomorphological features in the generic sense. However, the distinctions made in the lists obey to the different relevance biogenic processes may have on the geomorphology, such as bio-erosion or sediment fixation (Butler & Hupp, 2013; Cobo-Viveros & Cantera-Kintz, 2015; Gracia, Rangel-Buitrago, Oakley, & Williams, 2018; Willemsen, Horstman, Borsje, Friess, & Dohmen-Janssen, 2016). This is how sandy and hard bottoms are distinguished by the presence of biogenic coverage, such as corals, oysters, mussels, and seagrass. Similarly, the distinctions in the emerged units refer to differentiated vegetation coverage, such a mangrove, and creeping plants over dunes (M. L. Martínez, Gallego-Fernández, García-Franco, Moctezuma, & Jiménez, 2006; Willemsen et al., 2016). In this way, the importance assessment of processes on littoral configurations can make justice to the physical-biotic diversity of coastal environments.

Finally, the customized version for coastal environments of the conceptual diagram of the SHIELP model is depicted in Figure 5.8.

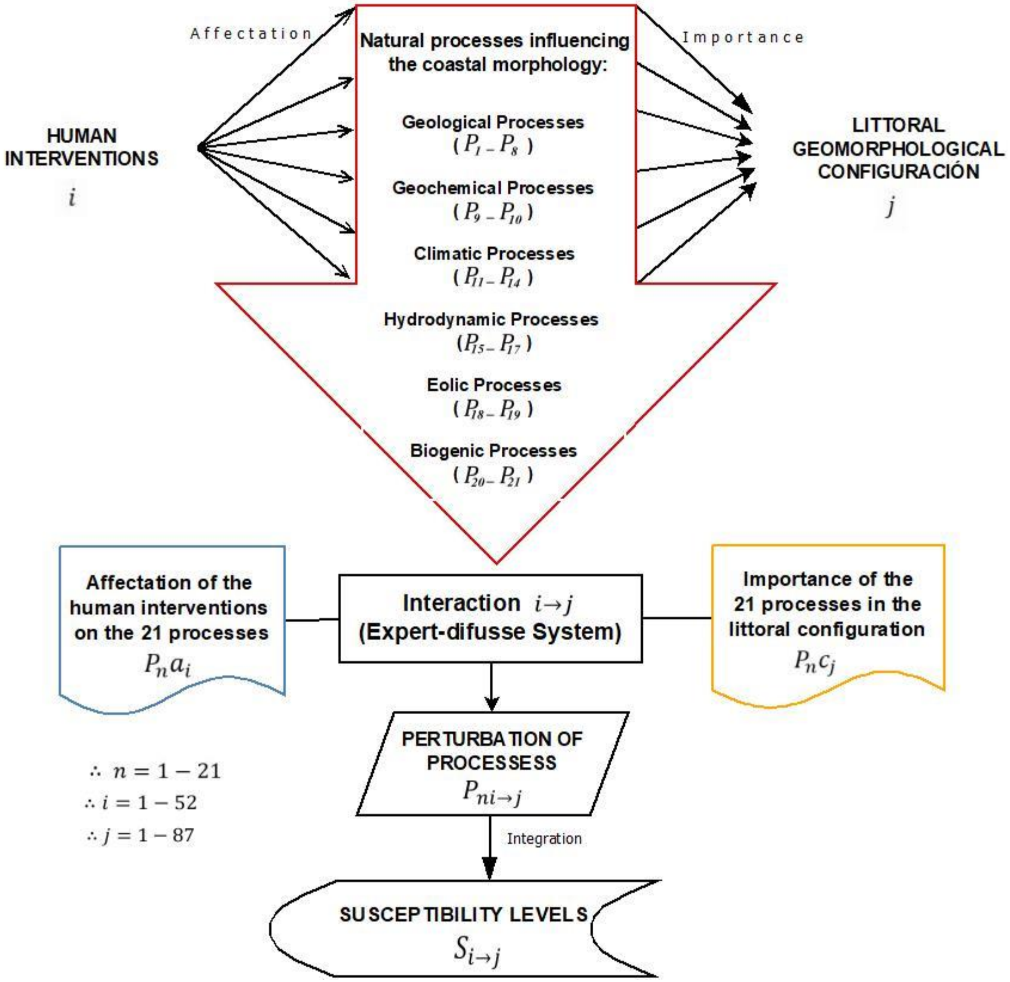


Figure 5.8. Conceptual diagram of the SHIELP for coastal environments

5.3.3. Matrix of processes' Importance of littoral configurations (see Appendix V-B)

The values compiled in the matrix of processes importance for the 87 configurations present a medium variability. The values range from 10.25 (~*Low-influence*) to 100 (*Determinant*) with a mean value of 61.07 and a standard deviation of 18.03. The configurations with the highest values of process importance are under the codes 24-BBD-SBV and 25-BVD-SBV, closely followed by 23-NBX-SBV and 26-BCT-SBV; all configurations comprising *Sandy bottoms with biogenic coverage* in the submerged part. The lowest values of process importance are under the codes 42-CTR- HBR, 43-CTN-HBR, 86-CTR-ROB, and 87-CTN-ROB; all comprising cliff or terraces in the emerged part of the littoral configuration. The boxplot diagram by processes (see Figure 5.9) reports the lowest mean value of importance (33.9) in *Physical weathering by structural controls* (P_4), despite presenting the higher dispersion of data within the series (23.5). Conversely, the processes of *Littoral erosion* (P_{15}) and *Wave generation by wind* (P_{18}) present the highest mean values (81.9 and 82.5 respectively), with low-medium dispersion in the data series (5 and 7.5 respectively). The process *Vertical* *movements associated with diapirism* (P2) reports the lowest dispersion within the data series (3.8) with a medium-high mean value (74). Therefore, the differentiated importance of the processes evidences the relevance of determining the type of geomorphological configuration when evaluating the susceptibility of an intervention.

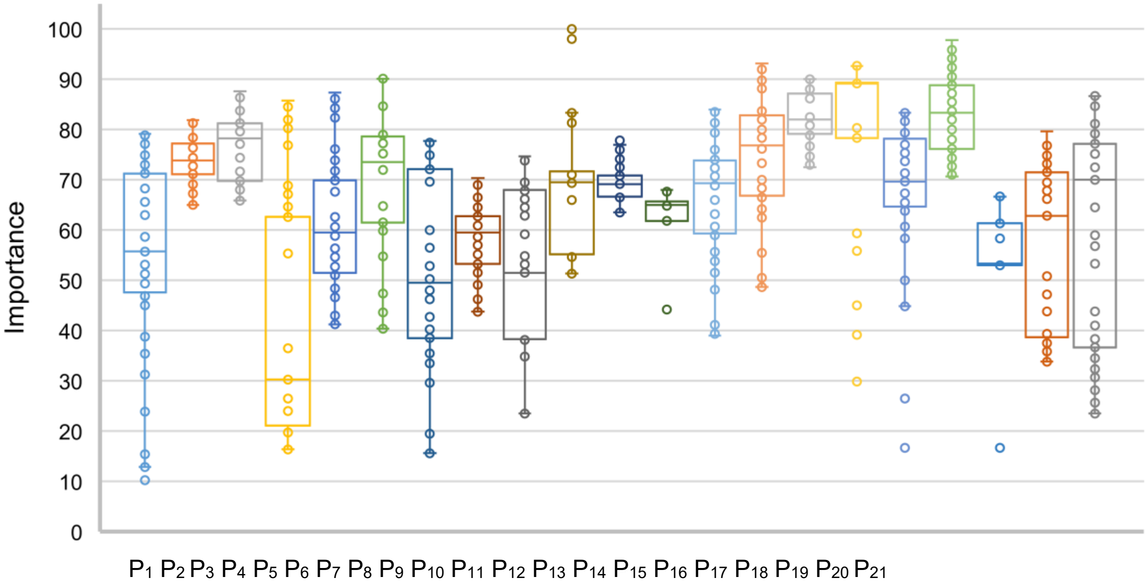


Figure 5.9. Boxplot of importance values set by processes in the importance matrix.

Another approach to analyzing the values on the importance matrix is through the linguistic equivalence of the same five ranges defined for perturbation levels in Table 5.5, where *Irrelevant* importance is equal to *None* perturbation and *Determinant* importance is equal to *Extreme* perturbation. At first, none of the processes received the qualification of *Irrelevant* for any of the 87 littoral configurations defined in the SIELP model for coastal environments. Conversely, all processes received the qualification of *High* importance in at least 16% of the configurations, being *Sediment transport and deposition by wind* (P19) the one reporting the lowest amount with the 14 configurations comprising dunes in the morphology composition. Other three processes were qualified with *High* importance in over 95% of the littoral configurations, namely *Earth movements by neotectonics* (P3), *Vertical movements associated to diapirism* (P2)*,* and *littoral erosion* (P15).

The qualification of *Low* importance is scattered among 9 processes, being *physical Weathering by structural controls* (P4) the one with a higher proportion of configurations (55%) and *Littoral sediment transport* (P16) the one with the lowest (5%). This last one is also the only process containing four out of the five qualifications of importance among all the configurations, with 14% under medium and 71% under high; the remaining 10% is concentrated in the littoral configurations with *Sandy offshore bars* on the marine part. Other processes qualified as *Determinant* are *wave generation by wind* (P18), *Drainage in the basin by weather events* (P_{14}), *Chemical weathering* (P_{10}) and *Erosion in the drainage basin* (P_6), with 21%, 15%, 9% and 4% of the configurations respectively. Lastly, the qualification of *Medium* importance was also scattered among all processes, except P_{15}, presenting the highest proportion of configurations (83%) in *Water table changes* (P_8) and *Littoral mass movements* (72%).

5.3.4. Matrix of processes' Affectation due to human interventions (see Appendix V-C)

The values compiled in the matrix of processes affectation by the 52 interventions present a high variability. The values range from 0 (zero; *Without*) to 100 (*Complete*) with a mean value of 12.11 and a standard deviation of 26.93. The intervention with the highest values of process affectation is *High-density settlements* (9-AHA) and the one with the lowest values is *Fishing* (21-FFF), which received by the expert cero values in nearly 40% of the processes. The boxplot diagram by processes (see Figure 5.10) reports the highest mean value of affectation (~35) in the processes within the hydrodynamic category (P_{15}, P_{16}, and P_{17}), with the highest dispersion in the data series (~32), which suggest a high variability. Conversely, the processes within the climatic category, specifically the three ones referring to global and wide regional scale (P_{11}, P_{12}, and P_{13}), report the lowest mean value of affectation by data series (~1.25) with a medium dispersion in two of them (P_{12} and P_{13}). The third one (P_{11}; *Eustatic sea level changes*), reports the lowest dispersion within the data series (2.3), with a low mean value (1.12). This suggests that the relevance of this process in individual human interventions is rather low, despite the worldwide concern given to the climate change phenomena within related. In sum, these results ratify that certain processes, such as the hydrodynamic ones, are more prone than others to be affected by almost all interventions.

A detailed observation of the affectation values in the same five ranges defined for perturbation levels in Table 5.5, where *without* affectation is equal to *None* perturbation and *Complete* affectation is equal to *Extreme* perturbation, complement the previous analysis. Unlike the importance matrix, the qualification representing the absence of the susceptibility attribute (*Without*) is spread out among all processes and interventions in the affectation matrix. However, such qualification is mostly concentrated on the climatic processes, where over 90% of the interventions were qualified as *Without* effect in the processes *Eustatic sea level changes* (P_{11}), *Semi-periodic sea level changes* (P_{12}) and *Extreme meteorological events* (P_{13}). The only interventions that register affectations different from *without* and *Low* in P_{12} and P_{13} were urban settlements (8-AHB and 9-AHA), qualified as high, and palatial settlements (10-AHP). Another intervention qualified as *Medium* affectation in P_{13} was *Sun, Sea, and Sand tourism* (12-EDF), which is consistent with often reports of meteorological events damaging housing infrastructure destined for tourist seasons at the seashore (La-Vanguardia, 2018; Rangel-Buitrago & Anfuso, 2015). The last process of the climatic category (P14; *Drainage in the basin by weather events*) presents a considerably lower proportion of interventions (67%) qualified as *Without* affectation, which suggest that this climate-related process is driven by local forces within the reach of individual human interventions.

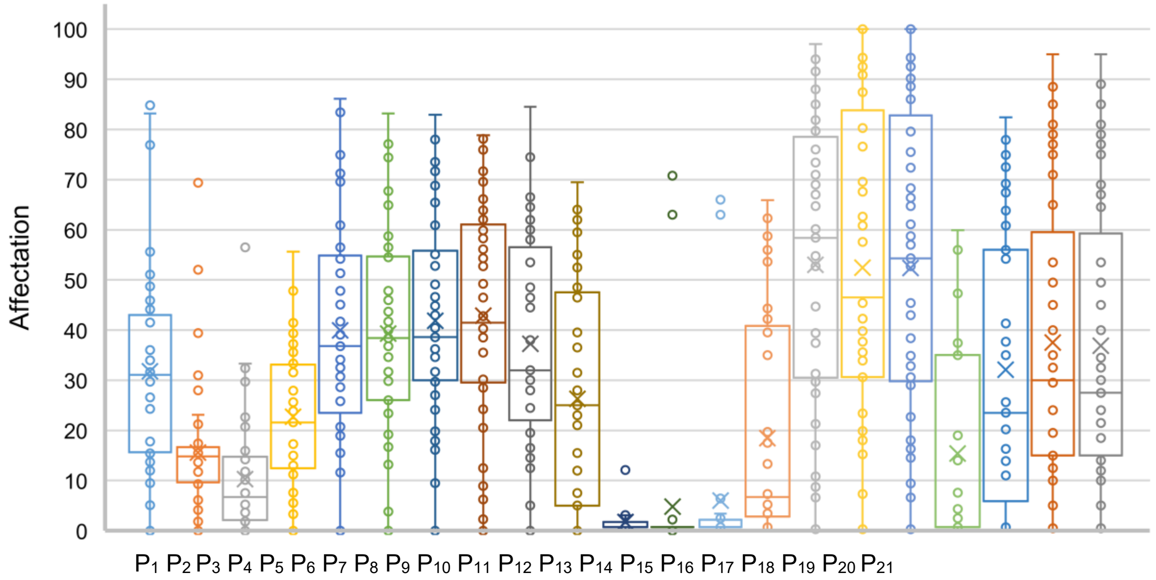


Figure 5.10. Boxplot of affectation values set by processes in the affectation matrix.

Other processes with a consistent pattern in the affectation matrixare *Earth movements by neotectonics* (P_3), which is qualified with *Without* and *Low* affectation in all interventions, except for one intervention qualified as *Medium* (32-GST; *Geological storage*). Similarly occurs with *Vertical movements associated to diapirism* (P2), which was qualified with *Medium* and *High* affectation in other two interventions (02-UWM; *Underground water movement* and 04-LUC; *land use changes*, respectively), while the remaining 49 interventions were qualified as *Without* and *Low* affectation. This distribution also implies that *Medium* and *High* qualifications are rather scattered alon with the remaining processes. Meanwhil, the rather scarce range values of *Complete* affectation are concentrated in one intervention (40-RDS) over the biogenic processes (P_{20} and P_{21}) and other 12 interventions over the three hydrodynamic processes; these last ones are distributed in three categories.

Therefore, hydrodynamic processes are the most sensible category within the processes of the SHIELP model for coastal environments. Over 50% of the interventions in the category *Marine navigation and facilities* (14-EMP, 17-EDM, 19-PUG, 20-SPS, 22-INA and 24-MMN) were qualified as completely affecting the hydrodynamic processes, which is consistent because they comprise structures directly interfering the littoral drift (e.g. piers, channels, and wave shelter). Other two interventions from the category of *Extractive activities* (37-DMI and 39-MDS) report the same level on affectation in the hydrodynamic processes, which may translate into leaks of sedimentary balance due to material withdrawal for aquatic traffic or economic purposes. On the other hand, the interventions on the category of *shore protection* regarding hard works (48 ROP, 49CYP, 50-MU, and 51-BNS) were also qualified as *Complete* affectation because they are designed to interfere with the littoral drift. It has been widely argued that this effect poses only localized solutions while triggering erosive trends in the surrounding locations (Botero et al., 2013; Rangel-Buitrago, Williams, et al., 2018; AT Williams et al., 2018). Therefore, it is understandable that the results in the affectation matrix would lead to strict controls on shore-protection works that heavily interfere in the hydrodynamic processes at regional scales.

Lastly, certain patterns in the qualifications ranges can also be identified for certain interventions in the affectation matrix. First, there is a group of three interventions that reports only qualifications of *Without* and *Low* affectation to the 21 processes, suggesting little relevance for the susceptibility scheme whatsoever. In ascending order, the intervention with the lowest affectation is *Solar energy plants* (28-SEP), with the qualification of *Without* in all processes, except for one reported as *Low* (P_{19}; *Sediment transport and deposition by wind*). The next interventions in the magnitude of affectation would be *Electric lines and facilities* (45-ELF), with 5 processes qualified with *Low* affectation (P_1, P_4, P_5, P_6, and P_7) and the remainder as *Without*. The third one in the group of interventions with little affectation is *Manufacture* (31-MAN), with 8 processes qualified with *Without* (P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_{19}, P_{20}, and P_{21}) and the remainder with *Low*.

On the other hand, there is another group of three interventions that reports the highest amount (13) of processes with qualifications above *Medium* affectation. The intervention with the highest qualifications are *Marine dredging* (39-MDS), with *Complete* affectation in the three hydrodynamic processes, *High* affectation in the two biogenic and two geologic processes (P_5 and P_7), and *Medium* in the two geochemical, three geologic (P_1, P_6 and P_8) and one climatic process (P_{14}). The next intervention in descending affectation order would be *Inlet navigation channels* (14-EMP), with the same pattern of *Complete* qualifications as before, but *High* affectation in one geologic process (P_7) and *Medium* in other nine processes (P_5, P_6, P_8, P_9, P_{14}, P_{18}, P_{19}, P_{20} and P_{21}). Finally, the intervention of *Solid waste exploitation and disposal* (53-SWD) lacks qualifications of *Complete* affectation, leading to five processes in the value range of *High* (P_9, P_{16}, P_{17}, P_{20} and P_{21}) and other eight in *Medium* (P_1, P_4, P_5, P_6, P_7, P_9 and P_{15}).

5.3.5. Susceptibility matrix

Given the 87 littoral configurations, with the 52 human interventions defined in the SHIELP model for coastal environments, a total of 4524 interactions (configuration vs interventions) were computed through the fuzzy logic toolbox of MATLAB. As previously stated, with the single susceptibility value computed for each one of the 4524 interactions comes a database of the perturbation level awarded by the 21 processes at each interaction. Therefore, a total of 95,004 perturbation level were computed through fuzzy logic. The compiled values of the coastal susceptibility to the effect of human interventions rest in a susceptibility matrix, that can be checked, along with the perturbation levels, in the digital Appendix V-D. As a summary, Table 5.10 registers the main descriptors of the susceptibility data set, along with the percentile ranges defined to categorize the five susceptibility levels set by the SHIELP model. The colored cells in this table represent the susceptibility levels and the overlapping of rows within indicating the limiting values of each range. Overall, certain patterns can be identified when looking at the data distribution by either of the two variables (configurations and interventions).

Table 5.10. Main descriptors of the susceptibility data set and equivalent ranges for susceptibility levels

Descriptor	Value	Susceptibility Level				
Minimum	13.25	Very Low				
10th Percentile	20,05		Low			
30th Percentile	23.56			Medium		
70th Percentile	29.08				High	
90th Percentile	34.24					Very High
Maximum	40.25					

Concerning the data distribution by interventions, three groups can be identified according to the particular susceptibility levels they can induce on the universe of littoral configurations (see Figure 5.11-left). On the one hand, over 17% of the interventions register one single susceptibility level regardless of the configuration over which they can be emplaced. Within this group, two interventions induce only *Very Low* susceptibility (21FFF and 28SEP), three induce *Medium* levels (15MUP, 18PUC, and 22INA), other three induce *High* levels (05MOC, 09AHA, and 53SWD) and one induce *Very High* levels (37DMI).

A second group of in interventions (~73%) reported the susceptibility levels in consecutive pairs, suggesting a modulating effect on behalf of the littoral configurations. Within this second group, 11% (N=4) report mixed *Very Low* and *Low* levels, 47% (N=18) registers *Low* and *Medium* susceptibility, and the 41% (N=16) is equally distributed in two groups: one of mixed *medium* and *high* levels, and the other of mixed *high* and *Very High* levels. The last group of five interventions (26GTP, 32GST, 36TPC, 42VFE, and 47CFP) reported three consecutive susceptibility levels (Very Low, Low and Medium). Finally, none of the interventions reported gaps between mixed levels of susceptibility.

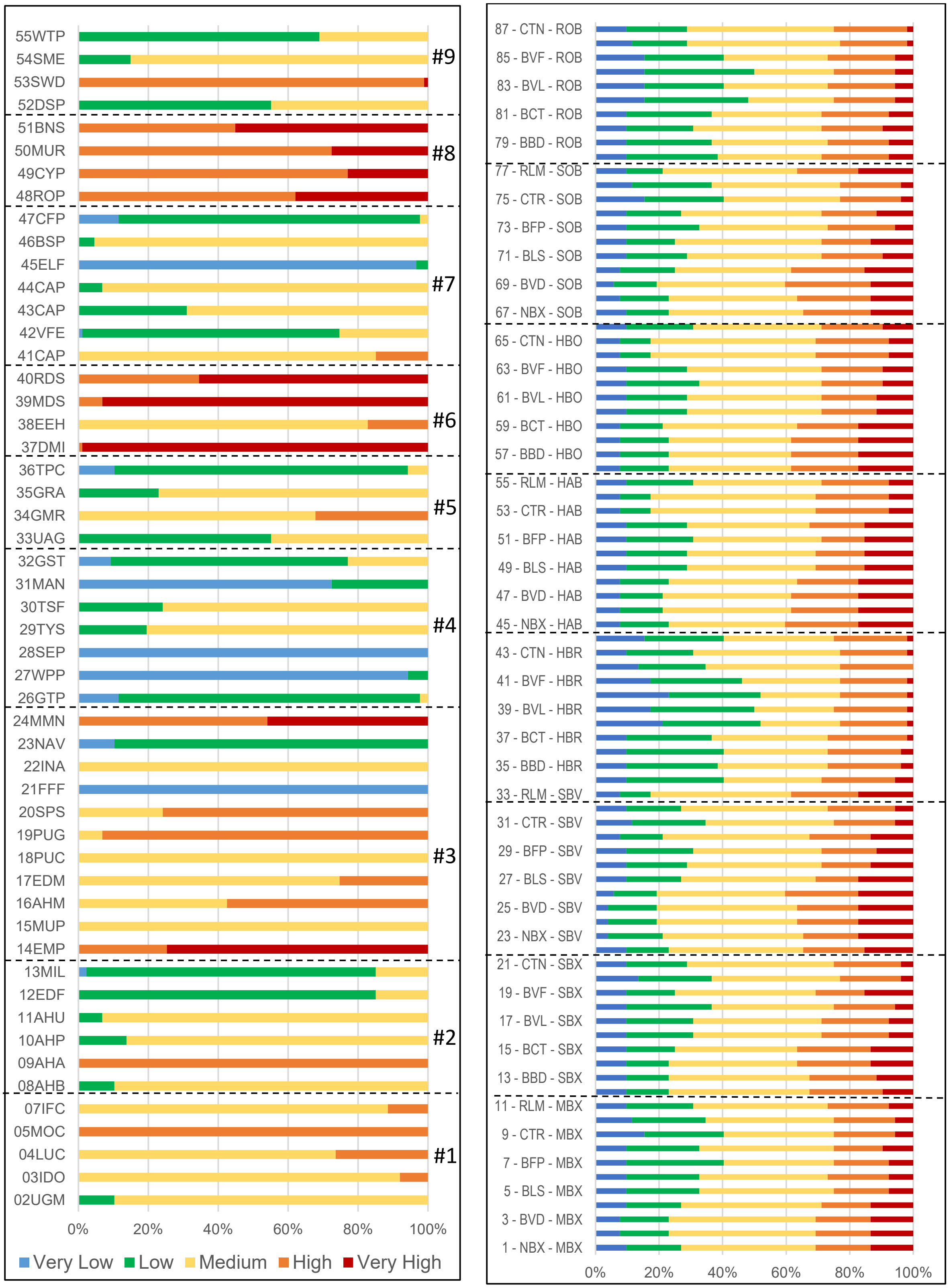


Figure 5.11. The proportion of susceptibility levels by interventions (left) and littoral configurations (right). The numbered segments on the left panel correspond to the nine categories of human interventions.

Additionally, the susceptibility levels depict a pattern regarding the nine categories of interventions, which the in Figure 5.11-left are segmented with dotted lines with numerals. The category with the highest susceptibility levels lies within the *Works of shore protection* (#8), with only the levels of *High* and *Very High*. Another group of intervention reporting *Very High*, high and *Medium* susceptibility levels is within the category of *Extractive Activities* (#6), which include one of the interventions reporting *Very High* susceptibility regardless of the configuration distinction (37DMI). A third category comprising interventions reporting all five susceptibility levels refers to *Marine navigation and facilities* (#3), which concentrate the highest figures on two interventions already highlighted in the results of the affectation matrix by its outstanding influence on hydrodynamic processes (14EMP and 24MMN).

Conversely, the lowest susceptibility levels are within the interventions of the category *Industry and energy installations* (#4), followed by the category of *Linear Infrastructure* (#7), and the category of *Extensive Land use and Livestock* (#5) with the one exception on mariculture (34GMR). Overall, the extreme susceptibility levels obtained in the model computations were consistent with the extreme qualifications of process affectation in the highlighted interventions of this results section.

Regarding the data distribution of outputs by configuration, susceptibility levels seem to respond to the nature of submerged morphologies, which are segmented with dotted lines in Figure 5.11-right. For instance, the group of configurations comprising hard bottoms without a biogenic component (e.g. HBR and ROB) exhibits the lowest proportion of *Very High* susceptibility figures. Meanwhile, the configurations with a biogenic component in the submerged morphologies (e.g. SBV, HAB, and HBO) present the highest proportion of higher susceptibility figures. This is most likely attributed to the sensitivity of living organisms to cope with disruptions on the natural dynamic equilibrium, such as in the geomorphology of coastal environments (Andrew Goudie, 2018; M. L. Martínez et al., 2006; E. Ramos, Díaz de Terán, Puente, & Juanes, 2016; Willemsen et al., 2016). More in detail, the two hard bottoms comprising a biogenic component (HAB and HBO) present a similar pattern in *Low* and *Medium* levels, while certain differences can be noticed in the *Very High* level. This dissimilarity may be rooted on a limited differentiated knowledge on the magnitude of the role played by biogenic and lithological components in the marine morphological evolution.

Finally, the susceptibility values here presented support the conclusions stated in Chapters III and IV, regarding interventions requiring a regional management framework. The inventory of human interventions in the continental Caribbean Coast of Colombia highlighted two W*orks of Shore Protection* within the ten most impacting interventions. These two types of structures outstand mainly due to the high frequencies of occurrences along with the extent of the gross study area. Similarly, the computed results of susceptibility state that the interventions category of shore protection works induce *High* and *Very High* susceptibility levels in all the littoral configurations of the SHIELP model. Similarly, interventions within the category of *Human Settlements* present *Medium* to *High* levels of susceptibility and construe the most concurrent and impacting in the Caribbean Coast (see AHU, AHM, AHB in Chapter IV). Therefore, the susceptibility values here presented support that such types of concurrent interventions require a higher level of environmental control, including environmental licensing instruments and its articulation with territorial planning instruments (e.g. regional shore erosion, urban expansion or land use).

5.3.6. Littoral configurations in the ECU Mag-Dique

The flowchart in Figure 5.12 summarizes the operations to prepare the geographical data of the study area to fit the parameters of the SHIELP expert-diffuse system in the variable of morphological configurations. Additionally, this diagram articulates the end product of the model architecture depicted in Figure 5.7 with the geographical representation through the database symbol. Consequently, these flowcharts provide a reference for eventual applications of the SHIELP expert-diffuse system in further coastal units, other than the ECU Mag-Dique. The following sections contain further detail of the results at each component.

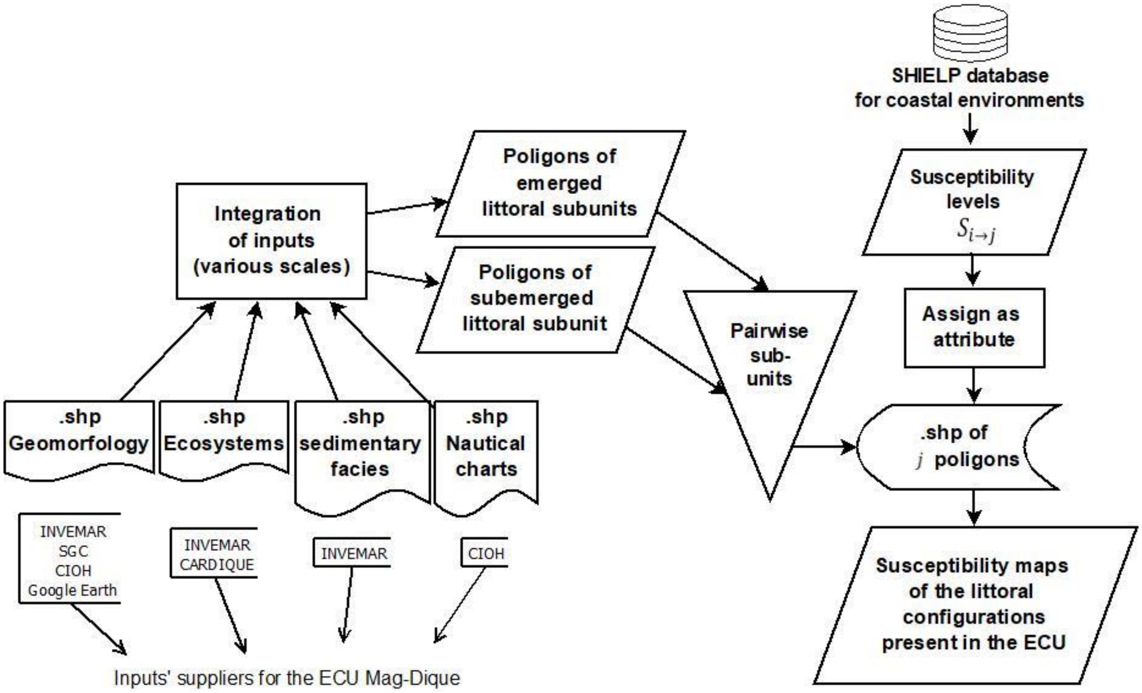


Figure 5.12. Generic flowchart of the SHIELP model architecture

Emerged subunits

The 11 **emerged compositions** defined for the SHIELP model for coastal environments were represented in the study area, through 146 polygons covering nearly 493 square kilometers of littoral areas. The results summarized in Table 5.11 show the highest occurrences and surface proportions within four subunits (RLM, BVF, BCT, and BVL) and the lowest in one (BVD), closely followed by other four littoral compositions (NBX, BBD, BLS and BFP). Comparing this values with the geographical location of the littoral configurations in the Map 01 (Appendix V-E), it is evident how the *Rivers or Lagoon mouths* (RLM) are widely distributed; although, the bays of Cartagena and Barbacoas concentrate the grossest area under this typology due to the extension of El Dique channel and its three sub-channels (Loquerica, Matunilla, and Correa). In these same locations are mostly concentrated the polygons of the composition *Beach & Cliff/Terrace* (BCT), which also spread along with some shoreline segments of the Atlantic department. The proportion area of this emerged composition is substantially low due to the inland extent of high coasts, whose definition at 40 meters from the cliff top was inspired in the protection zone established in the Cuban coastal law (GORC, 2000).

Table 5.11. Occurrences and coverage of the emerged subunits identified in the ECU Mag-Dique.

Emerged subunit		Occurrences (N)	Surface proportion
NBX	Naked beach	5	0.21%
BBD	Beach & Bare Dunes	5	1.23%
BVD	Beach & Vegetated Dunes	3	2.93%
BCT	Beach & Cliff/Terrace	22	1.38%
BLS	Beach & Lagoon/Swamps	5	0.89%
BVL	Beach & Vegetated Lagoon/Swamps	20	5.09%
BFP	Beach & Floodplain	5	1.74%
BVF	Beach & Vegetated Floodplain	27	66.07%
CTR	Cliff/Terrace of resistant rock	12	1.15%
CTN	Cliff/Terrace of Non-resistant rock	9	0.57%
RLM	River/Lagoon mouth	33	18.74%
Total		147	492.8 km^2

The second most representative composition comprises *Beach & Vegetated Floodplain* (BVF), whose polygons depict also the inner shores of large coastal lagoons covered with mangrove forests. Such are the cases at the CGSM lagoon system, the Tesca lagoon and some other minor lagoons in the Tierra Bomba island and Barú peninsula. Closing the group of high occurrences and coverage is the composition *Beach & Vegetated Lagoon/Swamps* (BVL), which spreads all along the study area because these polygons comprehend the morphologies neighboring the coastal wetlands on the seaside, rather than the full extent of the water body. On the other hand, within the subunits with the lowest representation in the study area are precisely the ones with the preferred cushioning system in shorelines of unconsolidated sediments: dunes (BVD and BBD). These morphological features were identified in the barrier-island of Salamanca, the barrier of the Tesca lagoon and in short segments of the northern Bolivar and middle Atlántico departments.

Submerged subunits

The results of **submerged subunits** ratify how the marine component of the littoral area is representative of coastal environments and yet undetailed in Colombia. Table 5.12 summarizes the number of submerged subunits identified in the study area, its occurrences (amount of continuous polygons) and the corresponding coverage. According to these results, only five of the eight compositions defined for the SHIELP model for coastal environments were represented through 55 polygons, which represent one third less than the emerged subunits. This proportionality, in favor of the emerged littoral diversity, calls attention to the level of knowledge of the marine floors of Colombia, where geomorphological processes have induced dramatic changes, related with concurrent submarine slides (Magdalena River pro-delta) and violent mud volcano eruptions (Galerazamba), both influencing the coastlines' configurations. Conversely, the overall coverage of the submerged subunits identified in the ECU Mag-Dique approximates to 3,000 square kilometers, which is close to six times more surface than the emerged subunits registered. This proportionality, now in favor of the submerged littoral areas, obey to the width determined by an indicative depth of closure at a regional extent (several hundred kilometers of shoreline). The 30-meter isobaths were defined as the submerged limit of littoral configurations, which translate into varying widths due to the changes on the continental platform along the study area.

Table 5.12. Occurrences and coverage of the submerged subunits identified in the ECU Mag-Dique.

Submerged subunit		Occurrences (N)	Surface proportion
MBX	Muddy Bottoms	21	56.67%
SBX	Sandy Bottoms	8	6.60%
SBV	Sandy Bottoms with Biogenic Coverage	10	16.16%
HBR	Hard Bottoms of bare rock	-	0.00%
HAB	Hard Bottoms with Active Biogenic Coverage	9	2.99%
HBO	Hard Bottoms of Biogenic Origin	-	0.00%
SOB	Sandy Offshore Bars	7	17.59%
ROB	Rocky Offshore Bars	-	0.00%
Total		55	2,842.3 km^2

The results summarized in Table 5.12 registers the three rocky subunits unidentified in the study area (HBR, HBO, and ROB), while the highest occurrence and surface proportion rely on *Muddy Bottoms* (MBX). Medium values are followed within two sandy morphologies (SBV and SOB) and the lowest coverage, with still medium occurrences, rely on two fairly different subunits (HAB and SBX).

Regarding the geographical location of the littoral configurations depicted in the Map 01 (Appendix V-E), the higher values on *Muddy Bottoms* (MBX) are justified by the extent of the large coastal lagoons marked in the geomorphological cartography of the study areas (CGSM and Tesca). Given the dimension of this features and the connection they keep with marine environments due to the saltiness reach, the aquatic section of this lagoons were assumed as closed seas with homogeneous composition of their floor sediments, namely fine sediments or mud. These assumptions were necessary to overcome the lack of clarity regarding the actual reach of the marine influence in large coastal lagoons while fulfilling the purpose of the SHIELP model for coastal environments without excluding a significant coastal feature that is particularly comprehensive in the ECU Mag-Dique.

Additionally, the MBX polygons are mostly concentrated in four continuous stretches, the longest one within the departments of Magdalena and Atlántico and the other three in the Bolivar department. This pattern may be attributed to the seasonal and hydrodynamic character of the marine currents spreading the fine sediments of the two mayor inland sources in the study area, the Magdalena river mouth in the northern and middle parts, and the Dique channel in the southern end (Moreno-Madriñán et al., 2015; J. Restrepo, 2008).

Sandy Offshore Bars (SOB) are the second submerged morphology with the highest surface in the study area, concentrated between the southern end of the Atlántico department and the northern end of the Bolivar department. This sector represents one of the shallower and extensive portions of the continental platform due to the deltaic lobe left when the Magdalena river emptied around the headland of La Garita, through Luruaco (Alvarado, 2007; Bernal, 1996; JO Martinez et al., 1990; Von-Erffa, 1973). Other two segments with this kind of morphology are within the bays of Cartagena and Barbacoas, whose limited circulation respect to open waters and copious sediment supply from El Dique channel also favor localized sediment accumulation (Moreno-Madriñán et al., 2015; J. Restrepo, Escobar, et al., 2016; Tosic, Martins, Lonin, Izquierdo, & Restrepo, n.d.).

Another subunit with similar conditioning as the previous one, due to the biogenic component, are *Hard Bottoms with Active Biogenic Coverage* (HAB). This code presents a medium occurrence, but substantially low proportion of surface (~3%). These polygons are mostly concentrated in the open sea side of the Tierra Bomba island and the Barú peninsula, along with the neighboring archipelago. There is uncertainty regarding the presence of these morphologies in the departments of Atlántico and Magdalena because the information layers available for these areas have limited detail. Lastly, Sandy Bottoms (SBX)has a medium occurrence and coverage in the study area without a particular geographical pattern. These subunits represent the portions of the marine floor whose composition is predominantly sand, according to the information layer of sedimentary facies.

Resultant littoral configurations

Given the options of emerged and submerged subunits identified in the study area, the amount of possible littoral configurations would be 55. However, according to the geographical location of subunits during the matching, the ECU Mag-Dique registers 154 polygons, representing 40 of the littoral configurations conceived for the SHIELP model for coastal environments. The results summarized in Table 5.13 indicate that patterns of littoral configurations are better correlated with the ones in the submerged subunits. This is mostly due to the substantially higher proportion of surface covered by the submerged subunits. As previously stated, the submerged reach of the littoral areas was set at an indicative depth of closure (30 meters isobaths), instead of the geographical reach set for the emerged subunits.

Therefore, four major groups of littoral configurations can be identified in descending order of coverage, which closely coincides with average occurrences, namely the configurations with sandy bottoms (SBX and SVB), *Sandy Offshore Bars* (SOB) and *Hard Bottoms with Active Biogenic Coverage* (HAB). The configurations comprising *Muddy Bottoms* (MBX) have the highest coverage (~58%) because it encompasses the off chart dimensions of the water surface of the CGSM lagoon system, with the equally extensive mangrove coverage (BVF) usually accompanying coastal lagoons. Even without the ~31% attributed to the CGSM, the group of configurations with MBX behold the highest coverage (~27%) and average occurrences (N=6).

In the second place are the configurations comprising both types of sandy bottoms (SBX and SVB), with a compiled coverage of ~20% and average occurrences of N=3. In the third position are the configurations comprising *Sandy Offshore Bars* (SOB), with coverage of ~15% and average occurrences of N=5. And the final position is within the configuration *Hard Bottoms with Active Biogenic Coverage* (HAB), with coverage of ~2.5% and average occurrences of N=2. Finally, the littoral configurations with cliff or terrace (CTR and CTN) as emerged subunits are the ones with the lowest surface representations due to the limited inland reach aforementioned. The coverage for these group of configurations is under 1%, except for the configurations comprising muddy bottoms, which are mostly concentrated in the Atlantic department.

Table 5. 13. Occurrences and coverage of the 40 littoral configurations identified in the ECU Mag-Dique

Configuration code	Occurrences (N)	Surface proportion
1 - NBX - MBX	3	0,7%
2 - BBD - MBX	4	2,7%
3 - BVD - MBX	2	1,6%
4 - BCT - MBX	9	2,5%
5 - BLS - MBX	3	2,3%
6 - BVL - MBX	7	4,1%
7 - BFP - MBX	3	0,6%
8 - BVF - MBX	13	34,7%
9 - CTR - MBX	4	1,0%
10 - CTN - MBX	4	1,0%
11 - RLM - MBX	13	6,5%
13 - BBD - SBX	1	0,2%
14 - BVD - SBX	2	0,8%
15 - BCT - SBX	2	0,5%
16 - BLS - SBX	1	0,0%
17 - BVL - SBX	1	0,3%
19 - BVF - SBX	5	1,0%
20 - CTR - SBX	4	0,1%
21 - CTN - SBX	2	0,7%
22 - RLM - SBX	4	2,7%
23 - NBX - SBV	2	0,9%
26 - BCT - SBV	5	0,8%
27 - BLS - SBV	1	0,9%
28 - BVL - SBV	6	3,8%
29 - BFP - SBV	2	4,4%
30 - BVF - SBV	3	0,6%
31 - CTR - SBV	2	0,1%
32 - CTN - SBV	3	0,3%
33 - RLM - SBV	5	1,5%
47 - BVD - HAB	1	1,5%
48 - BCT - HAB	2	0,1%
50 - BVL - HAB	1	0,1%
52 - BVF - HAB	5	0,6%
53 - CTR - HAB	2	0,1%
55 - RLM - HAB	2	0,1%
70 - BCT - SOB	7	1,9%
72 - BVL - SOB	2	2,6%
74 - BVF - SOB	6	3,6%
75 - CTR - SOB	4	2,3%
77 - RLM - SOB	6	4,3%
Total	154	3,326.8 km^2

Cartographic representation

The resultant map of the littoral configurations identified in the ECU Mag-Dique was designed and exported to a printing file from the software Arcgis 10.5. (2016). The geographical scale of the map is 1:250,000, which require the design of the map in the commercial size of 100x70 centimeters, with the portrait orientation to cover the full extent of the study area. The structure of the map was inspired in the format for presenting cartographic information defined in the general methodology for presenting environmental studies in Colombia (MAVDT), 2010). See the resultant Map 01 in the Appendix V-E.

The main section of the legend map contains the layers for the administrative division of the territory comprising the ECU Mag-Dique, the hydric net, the general boundary of the unit under construction by the Ministry of Environment, a frame index for the following maps that zoom into segments of the study area and the representative net lines of the emerged and submerged subunits. A complementary legend was placed inside the map containing the color code applied to the 40 littoral configurations identified, along with the feature count. Furthermore, all the input data cited in Table 5.6 are listed as sources in the cartographic base section, together with the reference to the official basic cartography used for the general context. Input layers and the final layer of littoral configurations for the study area were prepared in the reference system Magna Colombia Bogota, according to the guidelines of the National Geographic Environmental Data Storage Model (Resolution 2182 of 2016).

It is worth mentioning that the boundaries of the ECU, under construction by the Ministry of Environment, comprise a wider area than the littoral configurations identified. Such difference obeys to the scale difference in the criteria used, since the littoral configurations are specific for physic-biotic boundaries, while the general ECU follow additional socio-political conditions, such as the perimeter of urban centers and national protected areas (Decree 1120 of 2013).

5.3.7. SHIELP results for the ECU Mag-Dique

Given the littoral configurations delimited in the study area, the proportion of susceptibility levels present slight difference in respect to the general observations on the computations for the SHIELP model for coastal environments. Figure 5.13 compares the distribution of susceptibility levels in the littoral configurations present in the ECU Mag-Dique. One of the differences relies on the inclusion of nine new interventions (~15%) that induce a single susceptibility level regardless of the type of littoral configuration present in the study area, (see Figure 5.13-left).

Within this group, the two interventions (10AHP and 11AHU) in the category of *Edifications* (#2) steady for *Medium* susceptibility in all the ECU Mag-Dique, as well as the one intervention (29TYS) in the category *Industrial and energy installations* (#4) and the one (54SME) in the category *Basic sanitation facilities* (#9). Other two interventions (44CAP and 46BSP) in the category *Linear* *infrastructure* (#7) settled for *Medium* while a third one (45ELF) registers only *Very Low* susceptibility. Finally, one code (23NAV) of the category of *Marine navigation* (#3) steady on *Low* susceptibility levels, while the one intervention in the category of *Extractive activities* (#6) induce *Very High* susceptibility in all the ECU Mag-Dique.

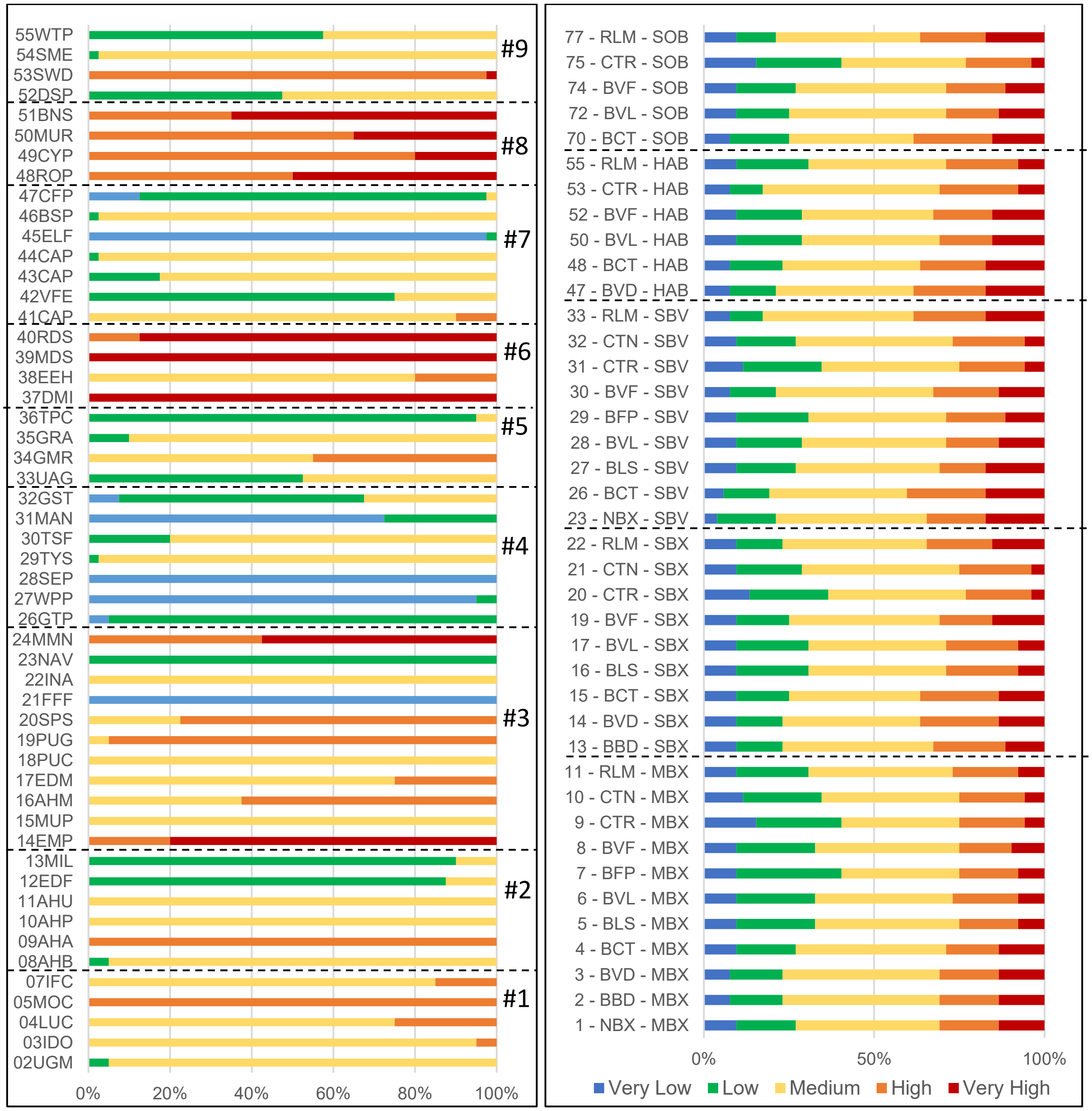


Figure 5.13. The proportion of susceptibility levels by interventions (left) and littoral configurations (right) in the ECU Mag-Dique.

On the other hand, the patterns regarding littoral configurations differ only by the absence of certain submerged morphologies. In absence of configurations comprising hard bottoms without a biogenic component in the study area, the group of configurations with the lowest susceptibility level transfers to configurations with muddy bottoms. Therefore, a safer ground for human interventions to be emplaced in the ECU Mag-Dique stands with littoral configurations comprising fine sediments and turbid waters, where rather scarce biogenic coverages take place (J. Restrepo, Zapata, Díaz, Garzón-Ferreira, & García, 2006).

Another result of the SHIELP model application in the ECU Mag-Dique relies on the cartographic representation of the susceptibility levels. The layout of the large scale map designed for the cartographic representation of the littoral configurations was used to consolidate the susceptibility values pertinent to the study area through a matrix inserted as the thematic legend (see Map 02 of Appendix V-E).

Additionally, reference and contextual elements of this large scale map were scaled and relocated into another layout in the commercial size of A3 (43,18 x 27,98) and portrait orientation. This layout accommodates 11 coastal segments to display the susceptibility results of the study area in higher detail, each representing a geographical scale of 1: 100,000 (see Maps 03 to 13 of Appendix V-E). The thematic legend in these detailed maps corresponds to the list of human interventions distributed in four sets, according to the susceptibility levels (Low, Medium, High and Very High), by each littoral configuration displayed. Given the extensive list of interventions and configurations, the alphanumeric code used to represent each variable is detailed in the Appendices V-B and V-C respectively. The thematic legend also indicates the environmental licensing instruments responding to each susceptibility level as detailed in the following section.

5.3.8. Application of the SHIELP model in environmental management

Screening and scoping criteria

The estimated susceptibility is here proposed as a technical criterion to screen the degree of environmental control required for certain interventions according to a location conditioning. In a comparative analysis among Latin-American and European countries, IDEA (2018) highlights the differentiation of licensing instruments as a strategy to categorize the environmental control of human interventions according to the significance of their environmental impacts. Differentiating criteria used in these countries (e.g. Costa Rica, Peru, Ecuador, Uruguay, and Spain) are narrowed to the environmental hazard, risk or potential impact. Therefore, the methodological approach of the SHIELP model here presented is an alternative criterion that integrates the intrinsic characteristics of the project, work or activity with the location particularities. Table 5.14 indicates the parameters defined to construe the SHIELP model's results with the screening and scoping stages of an ELP.

The two ends of the susceptibility ranges represent the extremes of environmental control, from no licensing instrument required to multiple assessments of environmental impacts. For instance, *Very Low* levels of susceptibility represent interventions with negligible perturbation to the natural processes configuring the intended geomorphological configuration for the project's emplacement.

Therefore, the control of impacts on these cases would not proceed under the competence of an environmental authority nor require a licensing instrument. The subsequent ranges of susceptibility values are paired with four types of environmental licensing instruments.

Table 5.14. Parameters for the interpretation of the SHIELP expert-diffuse system in a geographical region. EIS stands for Environmental Impact Study and NA stands for Not Applicable.

Screening			Scoping			
Susceptibility level	Licensing instrument	Competence	Documental review	Modeling with documental data	Field data	Modeling with field data
Very Low	None	None	NA	NA	NA	NA
Low	Environmental Viability (for concessions)	Regional Environmental Authority	$\boldsymbol{P_{ni\rightarrow j}}$= Medium & Low	$\boldsymbol{P_{ni\rightarrow j}}$= Extreme & High	NA	NA
Medium	Simplified EIS		$\boldsymbol{P_{ni\rightarrow j}}$= Low & None	$\boldsymbol{P_{ni\rightarrow j}}$= Medium	$\boldsymbol{P_{ni\rightarrow j}}$= High	$\boldsymbol{P_{ni\rightarrow j}}$= Extreme
High	Robust EIS	National Environmental Authority	$\boldsymbol{P_{ni\rightarrow j}}$= None	$\boldsymbol{P_{ni\rightarrow j}}$= Low	$\boldsymbol{P_{ni\rightarrow j}}$= Medium	$\boldsymbol{P_{ni\rightarrow j}}$= Extreme & High
Very High	Alternative analysis (multiple EIS)		NA	$\boldsymbol{P_{ni\rightarrow j}}$= None	$\boldsymbol{P_{ni\rightarrow j}}$= Medium & Low	$\boldsymbol{P_{ni\rightarrow j}}$= Extreme & High

The distinction within licensing instruments relies on an increasing degree of complexity for the elaboration of the technical study supporting the impact assessment. Such complexity translates into different types of input data required for the baseline definition, in which the perturbation levels computed in the SHIELP model are also paired to four degrees of information. The data requirements set as scoping criteria range from a simple documental review through more elaborated modeling and simulations to represent geomorphological processes. According to this proposed approach, the baseline definition of the technical study supporting the impact assessment structures the characterization of the geomorphological processes influencing the landscape evolution in a distinctive kind of environment.

First, the Environmental Viability is a technical document of low complexity because it represents a straight forward identification of impacts through a modest characterization of the project's influence area. This instrument is conceived to articulate environmental and territorial authorities in the context of land use planning, namely concession for occupying the public domain or for urban or industrial expansions. In this context, the Environmental Viability is a synthetic analysis of impacts, over which an environmental authority makes a pronouncement that is taken into consideration during the concession request. The main characteristic of this instrument is that the follow up of the project's responsibilities rest on the authority in charge of the concession (e.g. maritime authorities) instead of the environmental authority.

The next two licensing instruments, paired to *Medium* and *High* susceptibility levels, comprise a conventional Environmental Impact Study (EIS). The differentiating characteristics of these instruments rest on the environmental authority in charge of the follow up of the management compromises set by the license. In addition to this screening function, the two complexity degrees of the EIS correlate with differentiated information requirements for the baseline definition. However, further characteristics can be added to this differentiation, such as the periodicity of follow up reports for the control responsibilities of the competent environmental authorities (e.g. annual or biannual).

Last, the Alternative Analysisrepresents the instrument with the highest complexity because robust technical studies, with the highest levels of information, must be conducted on various technological and/or operational alternatives to the intended intervention. As a generic ELP stage, the examination of alternatives should include sufficient detail to facilitate the assessment of planned and unplanned impacts. (Durden et al., 2018; IAIA & IEA, 1999). Moreover, the common practice in several countries is to document this assessment in the technical report or EIS of every project or activity under environmental licensing (Joseph et al., 2015; Zhang et al., 2013).

However, the Colombian ELP restrict this analysis to few types of interventions, only with locations alternatives, through a distinctive instrument called 'alternative diagnosis' (Pereira et al., 2018; Toro, 2009). In this context, the most complex licensing instrument of the SHIELP model extends the reach of this alternative examination in Colombia to technological and operational options, instead of merely locative. In addition, such categorization is extended to interventions inducing the highest levels of susceptibility in a particular geomorphological configuration. Therefore, the Alternative Analysis requires the highest levels of information to perform a robust EIS for a set of technological and/or operational options for emplacing the intervention in the intended location.

Exemplification of scenarios

In order to grasp the potential application of the SHIELP model, Table 5.15 present eight scenarios enacting the screening and scoping stages of an ELP. These scenarios reflect how the perturbation levels computed for the processes in a given interaction rule as a scoping mechanism. The first four scenarios indicate how varies the scope of the information required for different human interventions regarding one type of littoral configuration (see the configuration examples on Map 03 of Appendix V-E).

Table 5.15. Information levels required from each process (Pn) in the environmental impact study (EIS), according to the type of licensing instrument. ***Doc. Review*** *stands for documental revision of external data;* ***Model (Doc.)*** *stands for modeling or simulation with documental data;* ***Field Data*** *stands for data collection through field surveys; and* ***Model (Field)*** *stands for modeling or simulation with field data.*

				P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}	P_{19}	P_{20}	P_{21}
Environmental Licensing Instrument		Interaction		GEOLOGIC								GEO-QUEMICAL		CLIMATIC				HYDRODYNAMIC			EOLIC		BIOGENIC	
		Inter-vention	Littoral configu-ration	Subsidence by sediment compaction	Vertical movements associated with	Earth movements by neotectonics	Physical weathering by structural controls	Littoral mass movements	Erosion in the drainage basin	Sediment sinking by geomorphological	Water table changes	Chemical formation of sediments	Chemical weathering	Eustatic sea level changes	Semi-periodic sea level changes	Extreme meteorological events	Drainage in the basin by weather events	Littoral erosion	Sediment transport	Littoral deposition	Wave generation by wind	Sediment transport and deposition by	Sediment production	Sediment fixation
Regional Authority	Environmental Viability	47CFP	**29-BFP-SBV**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**
		Perturbation level		Medium	Medium	Medium	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium
	Simplified EIS	11AHU	**29-BFP-SBV**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Doc. Review**	**Doc. Review**	**Model (Doc.)**	**Field data**	**Model (Doc.)**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Doc. Review**	**Model (Doc.)**
		Perturbation level		Medium	Medium	Medium	Low	Low	Medium	High	Medium	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Medium
National Authority	Robust EIS	05MOC	**29-BFP-SBV**	**Model (Field)**	**Field Data**	**Field Data**	**Field Data**	**Field Data**	**Model (Field)**	**Field Data**	**Model (Field)**	**Field Data**	**Field Data**	**Doc. Review**	**Doc. Review**	**Field Data**	**Field Data**	**Field Data**	**Field Data**	**Field Data**	**Field Data**	**Doc. Review**	**Model (Field)**	**Field Data**
		Perturbation level		High	Medium	Medium	Medium	Medium	High	Medium	High	Medium	Medium	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	High	Medium
	Alternative Analysis	39MDS	**29-BFP-SBV**	**Field data**	**Field data**	**Field data**	**Field data**	**Model (Field)**	**Field data**	**Model (Field)**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Model (Field)**	**Model (Field)**	**Model (Field)**	**Field data**	**Field data**	**Model (Field)**	**Model (Field)**
		Perturbation level		Medium	Medium	Medium	Low	High	Medium	High	Medium	Medium	Medium	Low	Low	Medium	Medium	High	High	High	Medium	Low	High	High

				P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}	P_{19}	P_{20}	P_{21}
Regional Authority	Environmental Viability	**12EDF**	23-NBX-SBV	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	Doc. Review	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**	**Doc. Review**
		Perturbation level		Medium	Medium	Medium	Low	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Medium	Medium
	Simplified EIS	**12EDF**	33-RLM-SBV	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Doc. Review**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Doc. Review**	Doc. Review	**Doc. Review**	**Doc. Review**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Field data**	**Doc. Review**	**Model (Doc.)**	**Model (Doc.)**
		Perturbation level		Medium	Medium	Medium	Low	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	High	Low	Medium	Medium
National Authority	Robust EIS	**24MMN**	08-BVF-MBX	**Field data**	**Field data**	**Model (Doc.)**	**Model (Doc.)**	**Model (Field)**	**Field data**	**Field data**	**Field data**	**Field data**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Model (Doc.)**	**Field data**	**Model (Field)**	**Model (Field)**	**Model (Field)**	**Field data**	**Model (Field)**	**Field data**	**Field data**
		Perturbation level		Medium	Medium	Low	Low	High	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Medium	High	Extreme	Extreme	Medium	High	Medium	Medium
	Alternative Analysis	**24MMN**	27-BLS-SBV	**Field data**	**Field data**	**Field data**	**Field data**	**Model (Field)**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Field data**	**Model (Field)**	**Model (Field)**	**Model (Field)**	**Field data**	**Model (Field)**	**Field data**	**Field data**
		Perturbation level		Medium	Medium	Medium	Low	High	Medium	Medium	Medium	Medium	Low	Low	Low	Medium	Medium	High	Extreme	Extreme	Medium	High	Medium	Medium

These scenarios exemplify how a littoral configuration with a biogenic component in the submerged part has the highest susceptibility to performing marine dredging (39MDS), while the conduction of fluids through pipelines (47CFP) induces the lowest susceptibility. Similarly, the modification of channels (05MOC) requires a robust technical study due to multiple processes under medium and high perturbation, while Luxury settlements (11AHU) would require a simplified assessment due to its punctual affectation.

Similarly, the last four scenarios in Table 5.15 represent the variation of the information requirements for two related types of interventions regarding different littoral configurations (see Map 03 of Appendix V-E for the configuration examples). These scenarios show how an on-land facility for Sun Sea and Sand Tourism (12EDF) induces higher susceptibility in an emerged morphology without cushioning system than in the morphological composition with a river or lagoon mouth, which differ in one process with high perturbation. Likewise, the emplacement of a Marina (24MMN) induces more processes in low perturbation over a configuration with muddy bottoms than in sandy bottoms with a biogenic component. In the main, these scenarios state that the lower the susceptibility, the less demanding are the information requirements for characterizing the influence area of an intervention during the prognosis of impacts.

Finally, this demonstration of the SHIELP model highlights a flexible character of the methodological approach it describes based on the susceptibility concept. For instance, if some processes are not present in the influence area of an intervention, the proponent can disregard it on the baseline definition, after a proper demonstration. In addition, even if the expert-diffuse architecture of the SHIELP model cannot be executed for an entire environmental management unit, the methodological approach summarized in Figure 5.7 (Section 5.3.1) can be used individually case by case. Regardless, the exercise presented in this research has generated a database of process perturbation that can be used as a technical guideline for customizing the terms of reference in real live cases involving the types of intersections (interventions vs littoral configuration) defined. Overall, the conceptual and methodological approach of the SHIELP model can be applied to any kind of environment with minor modifications.

5.4. Discussion

5.4.1. Natural processes influencing the coastal morphology

During the feedback of the questionnaires for rating processes importance and processes affectation, discussions emerged regarding the direction of the relationship between human interventions and processes dynamic. It was stated that certain geologic and climatic processes cannot be exclusively affected by human interventions. Instead, such relations are predominantly inverse when the processes are the ones threatening or conditioning human development. This dilemma focused mainly on the P_2 - Vertical movements associated to diapirism, P_3 - Earth movements by neotectonics, P_{11} - Eustatic sea level changes, P_{12} - Semi-periodic sea level changes, and P_{13} - Extreme meteorological events.

As inferred from the introductory conceptualization of this chapter, the relationship of geomorphology with human interventions can be described as bidirectional. This means that the direction “intervention on morphological processes” addresses the human impact, while the inverse direction focusses on the risks posed by the natural configuration to the integrity of the intervention (Cavallin et al., 1994). This last one is an integral part of the environmental impact assessment (Panizza, 1996b), which in the Colombian ELP refers to risk management and contingency plans. Therefore, instead of removing the six processes with the strong bidirectional noise from the parameter’s list of the SHIELP model, experts were asked to qualify them regardless the direction of the relationship process vs intervention in the affectation questionnaire.

The results compiled in the affectation matrix reflect the outputs of the previous analysis. For instance, the three climatic processes were qualified as *without effect* in almost all interventions due to the global scale (P_{11}), the intercontinental patterns of oceanic and atmospheric circulations (P_{12}), and the regional scale driven by gross geographical landscape and atmospheric patterns (P_{13}) (Bird, 2008; Kelletat, 1995). As for the two geological process embedded in the bi-directionality discussion, they were mostly qualified with *low* and *none affectation* within all interventions due to the unforeseen character of the tectonic activity and diapirism phenomenon (P_3 and P_2) (Kelletat, 1995; Masselink et al., 2011).

In the main, the bi-directionality approach allows maintaining all processes within the list of topics to be characterized in the baseline definition with differentiated levels of detail for the impact assessment. In fact, the active role of these natural processes advocates the traditional conception of the hazardous character of geomorphological processes on the EIA context (Panizza, 1996b), instead of just playing the passive role of enduring human affectation. Additionally, such bi-directionality, or passive-active role, of the natural processes articulate the scoping strategy proposed in the SHIELP model with the precautionary principles of the EIA (Durden et al., 2018; Joseph et al., 2015). For instance, even though an individual human intervention would hardly interfere in absolute sea level changes, by including the characterization of this process in a projects' influence area, developers are forced to foresee natural related risk and further territorial planning boundaries.

5.4.2. Morphological configurations of the SHIELP model for coastal environments

The research workshops conducted with the Geosciences program of INVEMAR provided pertinent contributions for setting the natural parameters of the SHIELP expert-diffuse system for coastal environments. At first, the Cuban legal code was introduced in the workshop discussions as a referent to build upon it the geomorphological parameters of emerged configurations. On the other hand, given the limited detail on marine morphological classifications (Finkl, 2004), the submerged subunits were articulated from the probable scenarios in all Colombian coasts (Pacific, Caribbean continental and Insular). In this way, the parameters of the SHIELP model may contribute to its suitability as an ELP technical licensing instrument in Colombia.

Regarding the emerged subunits, the Cuban legal system concerning coastal zone management was considered an appropriate reference in this proposal due to the detailed littoral classification it is based on. The decree-law 212 of coastal management in Cuba entails six types of coasts, such as terraces, cliffs, beaches, mangrove areas, river mouths and anthropogenically modified coast (GORC, 2000). Additionally, the beaches are subclassified according to the combination of this foreshore morphology with backing dunes, cliffs, and vegetation, which approximates to the littoral settings in most tropical coasts (Alcántara et al., 2014; Correa & Morton, 2010; Paniagua-Arroyave et al., 2018; Pranzini, 2004). Within this scheme, additional elements can be introduced in the mix, such as lagoon systems and floodplains (Milanes et al., 2019). Thus, this pattern of combining geomorphological features was adopted and enriched to define the 11 emerged littoral configurations set as parameters in the SHIELP model for coastal environments of tropical countries, such as Colombia.

Furthermore, as a regulatory framework, the Cuban coastal law is one of the most truthful to physical-biotic criteria governed by the Earth Sciences. The types of coasts in these regulation comprises basic characteristics of the morphological scenario as well as the reach of distinctive ecosystems (Barragan, 2003; Milanes, 2018). Aside from the similarities between Cuban and Colombian natural settings, as tropical territories, the Cuban coastal classification is already adapted for management purposes, such as integrated coastal zone management. This experience poses a strong argument over how geomorphological criteria can be effectively embedded into an environmental-related regulatory framework. Overall, the littoral classification scheme of the Cuban legal code recognizes that any attempt of coastal management should be modulated by the natural setting of the territory, which supports the **conceptual approach of the natural susceptibility to the effect of human interventions**.

Another element worth discussion relates to the availability and quality of geographical data. Int he absence of detailed marine cartography, the nautical charts played an important role in defining the limit and approximating the character or submerged subunits in the SHIELP model application for coastal environments. The nautical charts mainly allowed the identification of shoals, which differentiates two of the categories of marine morphologies (sandy and rocky offshore bars). Moreover, these nautical charts also allowed to recognize the geographical limit of the 30-meter isobaths, which was set as the boundary for the littoral configurations in terms of an approximate depth of closure. This limit, which is naturally inconstant, is conventionally used as the physical reach within which terrestrial and marine elements interact in the submerged part (Masselink et al., 2011). In other words, sea bottom sediments, commonly streamed from inland sources, are moved by the marine forces of wave (and tide influence) up until this depth of closure.

Complex computations are behind a precise definition of these limits, which varies accordingly with the wave climate. However, there is a generalization that allows estimating the depth of closure as half the wavelength (Sorensen. 2006). According to the wave forecast of the Caribbean Sea, performed by Lonin et al. (1996), the modeled wavelength for the study area ranges between 38 and 55 meters. These values suggest a generalize depth of closure within the 20 and 30-meters isobaths marked on the Colombian nautical charts. Although such estimation may be imprecise, it is sufficient to set a generalized limit to the subaquatic reach of littoral configurations for demonstrating the operation of the proposed SHIELP model at the regional extent of the ECU Mag-Dique. Nonetheless, further studies are required to update the knowledge about patterns of waves approaching Colombian coasts for future applications and updates.

Out of the former estimations, the deepest isobaths were selected as the offshore boundary of the littoral configurations to favor the unity of the georeferenced morphologies comprising a biogenic coverage, such as corals and seagrass. This reasoning agrees with the cellular and vector properties of the landscape because such morphological feature provides a distinction among the submerged subunits defined for the SHIELP model for coastal environments (Forman, 1995; Gracia et al., 2018). In addition, the regard for biogenic morphologies agrees with the principles of the ecosystem-based management, because it acknowledges the ecosystem integrity while addressing the human use of ecosystem good and services through an environmental licensing (Sarda, O'Higgins, Cormier, Diedrich, & Tintore, 2014). In this way, the environmental management proposed through the SHIELP approach acknowledges the integrity of physical and biotic relationships delimited in ecosystems. Overall, the physical component of a hydrodynamic boundary, such as the depth of closure, is complemented with an ecosystem criterion to set the reach of environmental impacts in the SHIELP model.

Regarding the compiled values in the three **matrixes** presented in the results, some precisions can be made regarding the differentiation of littoral configurations for the purposes of the SHIELP model. The results on the importance matrix reflect no particular pattern that would suggest homologous behaviors within the processes conceptualized for any of the submerged morphologies. On the other hand, the susceptibility values may suggest similar patterns within the configurations comprising a biogenic component in hard bottoms. However, without overcoming the knowledge limitations regarding the distinction of active biogenic coverage and biogenic origin, rocky marine floors in Colombia should still be differentiated under the precautionary principle of impact assessment (Durden et al., 2018; Joseph et al., 2015).

Some of the patterns identified in the susceptibility matrix reinforce some of the observations stated by variable (interventions and configuration) on each incoming parameter matrices (affectation and importance). Such is the case of nearly indistinctive qualifications between similar littoral configurations, only differentiated by lithological resistance or vegetation coverage. Even though the geotechnical properties of the rocks in high lying coast has proven relevant in erosional rates (Cobo-Viveros & Cantera-Kintz, 2015; Paniagua-Arroyave et al., 2018), the processes conceptualized in the SHIELP model for coastal environments comprehend a wider scope. In other words, while the susceptibility to the erosion focusses mostly on hydrodynamic processes and its conditionings (Mclaughlin & Cooper, 2010; Rangel-Buitrago & Anfuso, 2015; Reinen-Hamil, Hegan, & Shand, 2009), the SHIELP approach encompasses other five categories of processes customizing the coastal environment and its potential threats to human developments. Such double direction in the relationship between geomorphology and human developments is the essence of impact assessment (Cavallin et al., 1994), for which the perturbation level of the processes influencing the natural morphology provides a suitable scoping mechanism. Therefore, the similarities highlighted between the affectation and importance qualifications with the susceptibility values, regarding the incoming parameters of the expert diffuse system, reflect the consistency of the conceptual approach of the SHIELP model.

5.4.3. Littoral configurations of the SHIELP model in the ECU Mag-Dique

The ECU Mag-Dique is little less than a reflex of the situation of coastal information availability in Colombia. This region is the only one with a relatively high level of detail, such as the geomorphological maps at 1:25,000 scale from the research project on mud diapirism and coastal evolution in the Caribbean Colombian (Carvajal et al., 2010). This input was mainly responsible for having identified a substantial amount of continuous emerged subunits in the study area, almost three times higher than the submerged ones. And this brings to mind the even bigger limitations on data availability for Colombian seafloors where, once again, the ECU Mag-Dique partially contains higher detail on submerged cartographic information. Aside from general submerged ecosystem-related morphologies and presumable offshore bars from lows marked in nautical charts, there is no information regarding hard sea floors, nor any inventory of tombolo and stacks in Colombian coasts. Overall, the exercise of delimitating the littoral configurations in the study area made evident big gaps in marine morphological information.

Concerning partially detailed cartography, information available did not allow to distinguish among some typologies. Such was the case within the submerged morphologies of *Hard bottoms of Bare Rock* (HBR)*, Hard Bottoms with Active Biogenic Coverage* (HAB) and *Hard Bottoms of Biogenic Origin* (HBO). The only information input that gave any clues about the specificity of the origin of submerged configurations was the ecosystems' layer of IDEAM et al. (2007), which distinguishes the biogenic coverage of the seafloor. The polygons representing corals could only be cataloged as *Hard Bottoms with Active Biogenic Coverage* (HAB), given the tridimensional structure pulled by these organisms during the accumulation of stony coral skeletons (Kelletat, 1995; Pranzini, 2004). An additional input layer that gave further details in this coverages only comprised the sea floor of the department of Bolivar (INVEMAR & CARDIQUE, 2014). This layer distinguishes between shallow coral floors and shallow coral debris; the latter ones would represent non-active biogenic coverage. Nevertheless, the details in this additional layer did not contain data explicitly indicating hard bottoms without biogenic coverage and neither a distinction regarding the biogenic or lithological origin of such undefined hard bottoms. Therefore, future researches may address this limitation by specifying the biogenic and lithological role in marine morphologies for mapping the Colombian coastal bottoms.

Additionally, some uncertainty can be attributed to the net account for the offshore bars due to the lack of detail in the marine cartography. Although shallow continental platforms and enclosed water circulation would favor the accumulation of sandy bodies along the littoral drift (Masselink et al., 2011), the nautical charts over which the offshore bars were identified do not specify if the shallow features are of rigid or loose constituents. In lieu of further detail in the official data, the polygons drawn to represent offshore bars were all cataloged as "sandy" instead of "rocky". This assumption supports on the proximity of these features to the Magdalena River mouth, one of the major terrestrial sediments inputs in the Caribbean Sea (JO Martinez et al., 1990; J. Restrepo, 2008). Nevertheless, further research is required for more accurate characterization of the offshore bars, which would improve the pertinence of cartographic data for building the baseline of coastal environments for impact assessments.

On the other hand, many cases arose where emerged or submerged subunits comprised both lithological and biogenic elements. In these cases, the type of subunit selected for characterizing the littoral configuration in the ECU Mag-Dique favors the biogenic component due to its higher sensibility to natural or human-induced perturbations (J. Restrepo, Park, Aquino, & MLatrubesse, 2016). An even more complex situation involved the simultaneous presence of two biogenic typologies. For instance, coral and seagrass coverages are often joint features that represent two sets of the submerged subunits defined in the SHIELP model for coastal environments with a biogenic component, namely soft and hard bottoms respectively. In these cases, the predominant configuration was defined according to the higher coverage proportion and/or the higher proximity to the shoreline of the respective feature if coverages are even.

Conversely, mangrove coverages were construed in three types of emerged littoral compositions involving vegetated floodplains, vegetated lagoons, and river/lagoon mouths. In this last one, the mangrove coverage was often accompanied by a delimited fluvial plain and evidence of a permanent stream emptying the sea. In the cases of vegetation other than mangrove backing a beach without evidence of dune morphology, the emerged subunit was cataloged as the composition involving vegetated dunes (BVD) to approximate the parameters defined for the SHIELP model. In the main, the limited detail of the baseline information available induced several generalizations for applying the geomorphological criteria of the proposed model at the regional scale of the ECU Mag-Dique.

A final case word explaining regards the consideration of coastal lagoons as separate littoral configurations from the ones at the shoreline. Taking coastal lagoons as closed seas of muddy floors construe an extreme generalization to overcome unavailable or inexistent data. In fact, all cartographic inputs available for the study area classified the large wetlands of the CGSM and Tesca as coastal lagoons, without detailing the geographic extent of the marine influence of these features or the nature of their bottom's morphology. The CGSM, for example, has a virtually narrow separation from the shoreline through the barrier-island of Salamanca. Since this last feature has its own emerged littoral composition, it was separated from the large lagoon. Additionally, the salinity levels of the CGSM suggest an active interconnection with the sea all year long (Ibarra et al., 2014), while its surroundings of mangrove represent one of the littoral conventional configuration of its own (vegetated floodplain). This reasoning was then applied to most of the medium to large size lagoons in the delimitation exercise, not without stressing the need for further research to specify the reach of the marine influence in coastal wetlands for improving littoral cartography.

Lastly, the delimitation of emerged littoral subunits was richer than the submarine part due to the availability of three different geomorphological maps. Not only are more detailed the maps of Carvajal et al. (2010) for their graphical scale, but for the specificity coastal segments with urban coverage. The other inputs with the grosser scale depicted these areas bluntly as urban network, without differentiating any underlying geomorphology. Instead, the maps of Carvajal et al. (2010) recognized natural coastal features in these urban areas (e.g. beaches, dunes, mangrove, sand spits, terraces, abrasion platform) as well as anthropic filling. Since this last man-induced features are described in the legend's maps as former waterlogging terrains, the equivalent emerged feature was construed as a floodplain, appealing to the natural origin of the morphology. Putting aside the information quality of this input, the restriction of the owner institution regarding the geographical formats of the data increased the laborious task of the delimitation exercise, due to additional georeferencing, rectification and digitalization work.

On the other hand, the free imagery service of Google Earth proved a valuable contribution to the delimitation of emerged subunits. These complementary input has been successfully used in several types of research because it makes available and easy to manipulate a repository of high-quality images to observe the Earth relief and identify geomorphological units (Berry et al., 2014; Harris et al., 2014; Hossain et al., 2016; Magaña et al., 2014). The historical imagery tool of these image repository proved useful to distinguish the intermittence or permanence of water bodies and streams. On average, over 18 images are available for segments of the study area (graphical scales of 1: 20,000), comprising wet and dry seasons between the years 2000 and 2017. Such multi-temporal quality allowed to differentiate lagoons from floodplains, and river mouths from sporadic drains, which derived in a more precise definition of the emerged compositions comprising these features. In the main, the differentiated detail level of emerged and submerged littoral subunits in the ECU Mag-Dique demonstrate that the quality of results is proportional to the quality and availability of the cartographic inputs.

Finally, even though three out of the five submerged subunits could not be identified in the exercise for the ECU Mag-Dique due to the limited knowledge of Colombian marine floors, there is no conceptual basis to remove such unidentified configurations from the SHIELP model for coastal environments. Overall, the set of possibilities defined for the submerged component of the littoral configurations can still be represented in other coastal units from officially available data. But they can also be further detailed with field surveys during the characterization of the influence area of any human intervention in the littoral. Therefore, the conceptualization of the SHIELP model for coastal environments is sufficiently comprehensive and yet adaptable for future application in various coastal regions and individual assessments.

5.4.4. Combined system to estimate the geomorphological susceptibility to human perturbations

The expert-diffuse system designed for applying the susceptibility concept in the EIA context articulates expert knowledge with the properties of fuzzy sets' theory on the nature of human reasoning. On the one hand, the importance of natural processes on geomorphological configurations and its expected affectation by human interventions are rated by professionals with a degree of expertise in the area of geomorphology. This condition fits the character of an expert system, where determinations to specific situations rely on the analysis of trained professionals in a field of knowledge (Liu & Lai, 2009; Suhartono, Aditya, Lestari, & Yasin, 2013). On the other hand, a fuzzy system has proven capable to manage uncertainty and provide a numeric score to describe a complex system with imprecise information (Canavese et al., 2014; Mardani et al., 2015). Such is the case of estimating the susceptibility to the effect of human interventions, where the understanding of several geomorphological processes is rather incomplete and their quantification is out of reach due to resources' limitations, both technological and informational (data availability).

One of the uncertainties of the susceptibility estimation regards the difficulties to assess the response of geomorphological processes to human perturbations. In the proposal of quantitative indicators for assessing impacts on consumable and non-consumable geomorphological resources, Rivas et al. (1997) exclude the geomorphological processes because of its dynamic nature difficult real-world application of conceptual and methodological frameworks. This uncertainty is managed in the SHIELP model through the linguistic approach upon which fuzzy logic systems rely on. The natural language used by experts to rate processes' affectation and importance, such as the labels *Irrelevant-Low-Medium-High-Determinant*, represent fuzzy boundaries of the set to which qualifications *do* or *do not* belong.

Another uncertainty managed through the fuzzy logic computation strategy of the SHIELP model is the imprecise human nature of the experts' opinion. It has been stated that individuals may report diverse judgments of an event due to different subjective perceptions or personalities, even using the same words (Mardani et al., 2015). In this sense, the linguistic variables provide adequate mathematical representations of vague concepts that cannot be limited by exact boundaries, which is a common property among the variables used in environmental assessments (Peche & Rodríguez, 2011). Moreover, fuzzy sets are capable of representing linguistic information, as well as imprecise concepts, such as the SHIELP model parameters of process' affectations and importance (Canavese et al., 2014). Therefore, the sliding bar used in the questionnaires administered to the experts on coastal geomorphology provides an appropriate capture strategy of their linguistic opinion. These type of questions registers numerical answers while using linguistic indicator for representing the meaning of the two ends of the sliding bar. In this way, the numeric format, in which the answers are directly recorded, serves well in the fuzzification phase that computes processes' perturbation in the SHIELP model.

Regarding the inference rules defined for the fussy logic computation strategy of the SHIELP model, it is worth noticing a differentiated relevance of the two incoming parameters depicted in Figure 5.3 (Section 5.2.2). The rules registered in Table 5.3 (Section 5.2.2) indicate that the process' affectation prevails over the process' importance because they follow the logic on environmental impact. Such logic favors the effect of a project over the environment, rather than the effect of the environment on the project, which is a better fit for environmental risk considerations (Cendrero et al., 2001). Even though environmental assessments comprehend both, impacts and risks, the susceptibility approach here introduced is more incisive on the man to landscape relation, without ignoring the counterpart.

Finally, the SHIELP model is subject to improvements, through the articulation of data processing tools in its architecture. For instance, neuronal webs and multivariate statistics can contribute to future validations of SHIELP and advance techniques for transitional computations, respectively (Castley et al., 2003; Robles et al., 2017). On one side, a neuro-diffuse approach would evolve the model into an automatized system that can be trained with past experiences (e.g. records of approved and denied licenses), as well as learn from ongoing and future experiences where the model is applied. On the other side, multivariate techniques of information reduction, such as principal components, may be an advance strategy to integrate the multiple perturbation levels of geomorphological processes into a single susceptibility value. Therefore, the multivariate statistical analysis provides an alternative to the current weighted average used in the model to integrate the various outputs of the fuzzy logic routine on geomorphological processes. In the main, the challenge of adding sophistication and conciseness to the SHIELP expert-diffuse system relies on the realm of computation and informatics sciences.

5.4.5. The applicability of the SHIELP model

Improvement to the Colombian ELP

The screening and scoping scenarios exemplified in Table 5.15 (Section 5.3.8) assert the consistency of the SHIELP model to address the deficiencies in the common practice of environmental assessments in Colombia. As stated in chapter II, Colombia lacks a criteria-based procedure for screening projects in the ELP and its scoping mechanism barely discriminates interventions from different nature, less alone kinds of environments (Pereira et al., 2018). According to Durden et al. (2018), there are four screening approaches to determine the need for an EIA: **a)** generalized preliminary studies across industry or area; **b)** case-by-case individually assessed; **c)** established list; and **d)** by thresholds based on limits according to predefined criteria. Therefore, the screening of interventions for EIA can follow arbitrary principles or technical definitions based on methodological paths.

In this context, the screening approach in Colombia can be described as a combination of **a)** and **c)** because it establishes a list of interventions requiring an environmental license, but it is currently being updated through a generalized early environmental evaluation of economic sectors (IDEA, 2018). On the other hand, the proposal of the SHIELP model would categorize as an adaption of the approach **d)**, in which the level of detail of the impact assessment is screened though criteria and thresholds (Jay et al., 2007; Wood C., 2003). In this sense, the SHIELP model set the estimated susceptibility as a criterion and the percentile ranges as thresholds to ascertain the level of complexity required for the environmental control of one human intervention through a licensing instrument. In other words, the four licensing instruments emulating levels of environmental control are set by a measure of the natural susceptibility to human perturbations in a particular geomorphological setting. And such limits or thresholds obey to predefined criteria of the human affectation and natural relevance of the geomorphological processes influencing a particular kind of environment.

In addition, previous researches state that screening outcomes should determine the basis for the scoping, as the consecutive ELP phase (Durden et al., 2018; Joseph et al., 2015). This concatenation is precisely reflected in the SHIELP model as well because each licensing instrument is paired with distinctive degrees of information requirements according to their complexity level. Regarding the information levels used in the SHIELP model for the baseline definition, the documental review refers to existing data, while field data collection and modeling from either information source classify as the generation of new data (Durden et al., 2018).

In essence, scoping identifies the key issues that should be covered in the impact assessment and sets the terms of reference for the technical study supporting the licensing procedure (IAIA & IEA, 1999; Joseph et al., 2015). The applicability of the SHIELP model relies on customizing these terms of reference, according to the particularities of the interaction between a characteristic landform with a type of human intervention. By corresponding the degree of detail required in the baseline definition with the perturbation level at each geomorphological process, the model recognizes the resilience of the environment and the characteristics of the human intervention triggering the changes in the system (IDEAM, 2001; Toro et al., 2012). These are the elements of the susceptibility concept defined in the introduction. In the main, the implementation of the SHIELP model in the Colombian ELP would improve some of their fundamental deficiencies in the operation of EIA best practices.

Finally, the flowchart in Figure 5.14 represents the path that an environmental authority can follow to use the SHIELP model as a screening strategy and as a technical guideline to set specific terms of reference for scoping the technical studies that support the impact assessment. The practical reading of this decision tree is as follows:

> *"the susceptibility value of a given intervention in a given configuration (interaction) would fit a percentile range that places its environmental control into a territorial competence (regional or national), and through a specific licensing instrument with differentiated requirements of information for the baseline definition"*

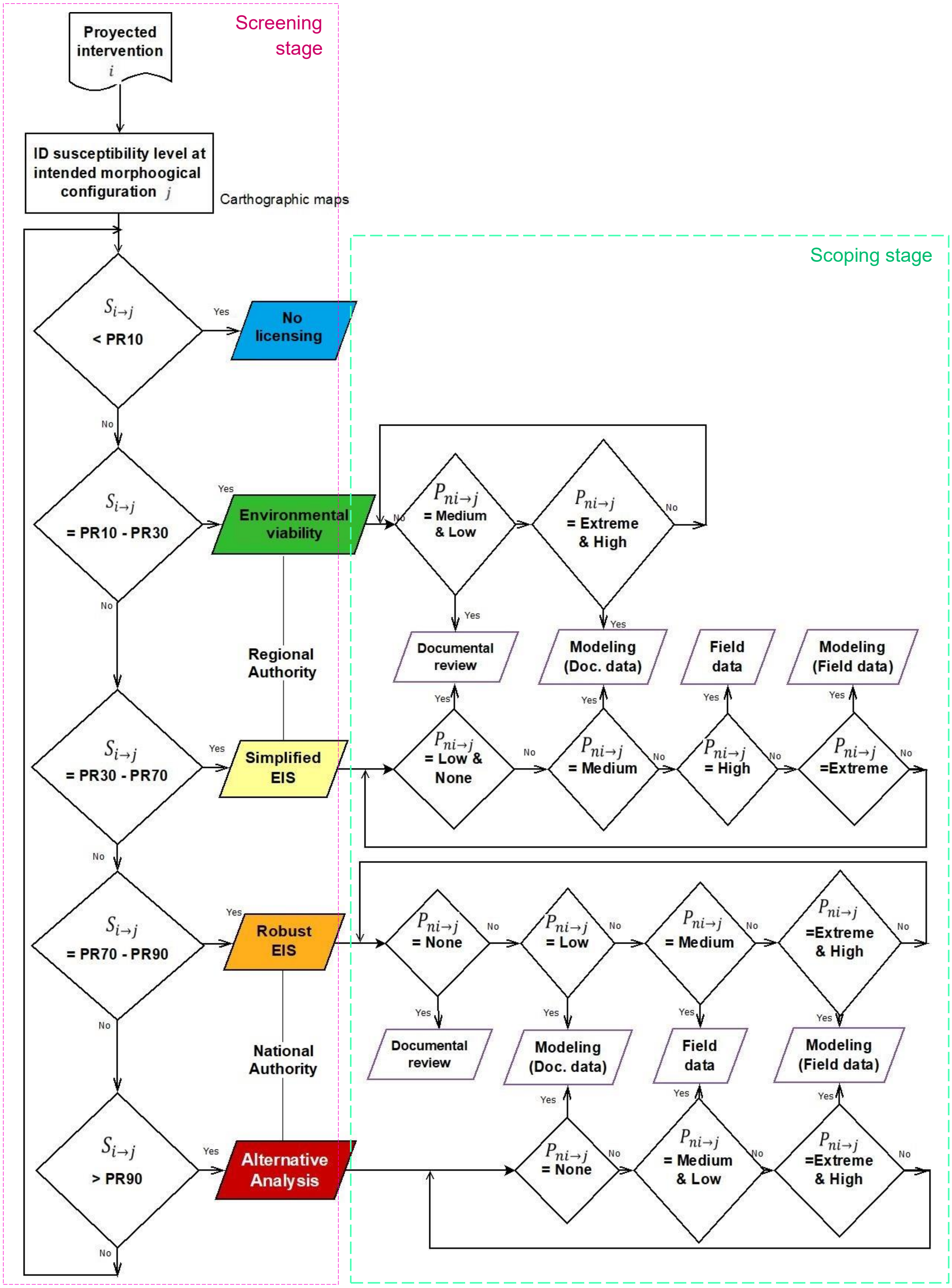


Figure 5 14. Flowchart of the operation of the SHIELP model results by an environmental authority

Comparison to ongoing proposals

A similar approach of differentiated environmental licensing has been formulated for the Colombian system as part of a consultancy work developed by the Environmental Studies Institute of the National University for the Ministry of Environment (IDEA, 2018). Among the adjustment proposal to the Colombian ELP, this work classifies the list of projects or activities under environmental regulation into three types of licenses. Such discrimination is based on the assessment of the Potential Environmental Impact (PEI) of every project, work or activity, according to the qualitative method of Toro et al. (2013).

This method considers generic environmental factors, both physical and societal, namely air quality, the agricultural capacity of the soil, water quality, land use changes, flora and fauna diversity, habitats, social security, population, employment, and educative resources. Similar to the susceptibility levels in the SHIELP model, ranges of PEI values are used to discriminate the type of licensing with increasing complexity level. It is worth noticing that this consultancy work was conducted almost simultaneous to the present research on the conceptual approach of susceptibility to the effect of human interventions. Table 5.16 compares the estimated values of susceptibility from the SHIELP model and the estimated PEI from IDEA (2018), over the list of human interventions on coastal environments.

The main difference between these proposals of differentiated environmental licensing rely on the number of thresholds and instruments. The SHIELP uses five levels with four licensing instruments, making the lowest level a threshold to screen projects not requiring an environmental licensing. Meanwhile, IDEA (2018) consider three levels with three licensing instruments, although nearly 50% of the interventions with effect on coastal environments are not included in the assessment. Over 15% of the interventions present coinciding levels within the estimated criteria (e.g. 03IDO, 18PUC and 41CAP), while the remaining 35% present differences comprising even opposite levels. Outstanding examples of these extremes differences are within the works of shore protection and stabilization, including inlet navigation channels (14EMP) that behave similarly. One of the reasons for these discrepancies is the attention to detail given by the SHIELP approach to the locative particularities governed by geomorphological processes. Another reason is the consideration of social impacts within the PEI estimations, which are not reached by the SHIELP model.

Table 5.16. Comparison between susceptibility and PEI (Potential Environmental Impact) as screening criteria of licensing instruments for Colombia.

Human interventions on coastal environments			Susceptibility (SHIELP)	PEI (IDEA, 2018)
Drainage basin alterations	02 UGM	Underground water movement	🟩🟨	
	03 IDO	Irrigation districts	🟨🟧	🟨
	04 LUC	Changes in land use (deforestation)	🟨🟧	
	05 MOC	Modification of channels	🟧	🟨
	07 IFC	Installations in fluvial causes	🟨🟧	
Edifications	08 AHB	Low density settlements	🟩🟨	
	09 AHA	High-density settlements	🟧	
	10 AHP	Palatial settlements	🟩🟨	
	11 AHU	Luxury settlements	🟩🟨	
	12 EDF	Sun, Sea and Sand Tourism	🟩🟨	
	13 MIL	Military installations on land	🟩🟨	
Marine navigation and facilities	14 EMP	Inlet navigation channels	🟧🟥	🟩
	15 MUP	Public Docks	🟨	
	16 AHM	Luxury settlement with pier	🟨🟧	
	17 EDM	Sun, Sea and Sand tourism with pier	🟨🟧	
	18 PUC	Deepwater ports without shelter	🟨	🟨
	19 PUG	Shallow water ports without shelter	🟧	🟨
	20 SPS	Sheltered ports	🟨🟧	
	21 FFF	Fishing	🟦	
	22 INA	Naval military installations	🟨	
	23 NAV	Internal Maritime Transport	🟦🟩	
	24 MMN	Marinas	🟧🟥	
Industrial and energy installations	26 GTP	Geothermal plants	🟦🟩	🟨
	27 WPP	Wind power plants	🟦🟩	🟨
	28 SEP	Solar energy plants	🟦	🟨
	29 TYS	Thermoelectric plants	🟩🟨	🟧
	30 TSF	Transformation/storage of fossil fuel	🟩🟨	🟨
	31 MAN	Manufacture	🟦🟩	🟧🟨
	32 GST	Geological storage	🟦🟩🟨	
Extensive land use/livestock	33 UAG	Livestock and farming	🟩🟨	🟨
	34 GMR	Mariculture	🟨🟧	
	35 GRA	Aquaculture	🟩🟨	
	36 TPC	Thematic parks and camping	🟦🟩🟨	
Extractive activities	38 EEH	Explore/extract hydrocarbons	🟨🟧	🟧
	39 MDS	Marine dredging	🟧🟥	🟨
	40 RDS	River dredging	🟧🟥	
Linear infrastructure	41 CAP	Roads, double roads, bridges…	🟨🟧	🟧🟨
	42 VFE	Railways and facilities	🟩🟨	🟨
	43 CAP	Tunnels	🟩🟨	🟨
	44 CAP	Airports and runways	🟨	🟧🟩
	45 ELF	Electric lines and facilities	🟦	🟨
	46 BSP	Basic sanitation pipes	🟩🟨	
	47 CFP	Conduction of fluids (pipelines)	🟦🟩	🟨
Shore protection Works	48 ROP	Breakwaters and artificial reefs	🟧🟥	🟩
	49 CYP	Groins	🟧🟥	🟩
	50 MUR	Sea walls, walks, and ridges	🟧🟥	🟩
	51 BNS	Beach nourishment	🟧🟥	🟩
Basic sanitation facilities	52 DSP	Desalination plants	🟩🟨	
	53 SWD	Solid waste exploitation/disposal	🟧	🟧🟨
	54 SME	Submarine emissary	🟩🟨	
	55 WTP	Wastewater treatment plants	🟩🟨	🟩🟨

No environmental licensing	🟦 Very low	
Environmental viability	🟩 Low	Type I
Simplified EIS	🟨 Medium	Type II
Robust EIS	🟧 High	Type III
Alternative analysis	🟥 Very High	

↑ └ **Levels** ┘ ↑

└ **Licensing instruments** ┘

The added value of the SHIELP model from this previous proposal of differentiated licensing instruments rest on customizing technical requirements for assessing the impact of human interventions, according to the geomorphological particularities of a kind of environment. The methodological approach of susceptibility, based on the perturbation of the natural processes configuring the landscape evolution, sets screening and scoping criteria for particular interactions between interventions types and landforms. The results the SHIELP model for coastal environments on Section 5.3.5 reflect how littoral configurations are more or less prone to experience affectation due to distinctive man-induced changes on the flow of matter and energy along with this kind of environment. Therefore, the derived technical guideline from this susceptibility approach, based on geomorphological processes, not only recognizes the intrinsic characteristics of the human interventions but also the character of the natural system describing its resilience.

Regarding consecutive ELP stages, other than screening and scoping, some potentialities can be identified within the SHIELP model. Intermediate results of the expert diffuse system may contribute to the improvement and innovation of impact assessment methodologies, which are often under scrutiny due to the lack of scientific robustness (Joseph et al., 2015). In the Colombian context, for example, methods often accepted by users and stakeholders are highly reliant on subjective inputs and incapable of producing useful outputs according to the technical content and volume of the baseline information. (IDEA, 2018; Toro et al., 2010). In this sense, the perturbation levels and corresponding weights conceived in the SHIELP model´s architecture may be a referent in balancing the relative importance or acceptability of residual impacts.

For instance, in an existing qualitative methodology of impact assessment, the significance of presumed impacts can be set according to the weights assigned to the perturbation level of every process affected by human action. Such prioritization of environmental damage can score the degree of loss of ecosystem services due to human interventions, once the designed management measures have been applied. The resultant net loss of ecosystem services (waste regulation, climate regulation, protection from environmental hazards and opportunities for recreation) could be the ultimate criteria for the decision making over the environmental licensing.

Limitations of the SHIELP model application on coastal environments and future work

The results of the ECU Mag-Dique (Section 5.3.6) stress that several generalizations on the demonstration of the susceptibility approach obey to the large graphical scale of the study case (3,335 square kilometers of littoral areas). To address this limitation, the SHIELP model for coastal environments can be improved by including the component of physiographic units and/or littoral cells. Such criterion for coastal segmentation considers the inwardly cushioning effect provided by neighboring areas in the dynamic equilibrium of coastal environments (Masselink et al., 2011;

Pranzini, 2004). Taking the analogy of coastal dunes as the saving account of sediments for when a beach faces losses in the across shore balance (R. G. D. Davidson-Arnott, 2005; J. Gomez et al., 2017; Gracia et al., 2018; M. L. Martínez et al., 2006), in the longshore sense adjacent littoral configurations play a similar role. It means that littoral cells also work as a provider and/or recipients in a grosser balance (Anfuso, Martínez-del-Pozo, & Rangel-Buitrago, 2013; Anfuso et al., 2011; Bezzi et al., 2018; Inman, 2005). Therefore, clustering littoral configurations into coastal compartments would favor a better classification of the estimated susceptibility in an environmental unit.

Introducing this physiographic component in the SHIELP model would provide a systemic criterion to articulate and polish the level of environmental control required for human interventions in particular coastal configurations. As stressed by the affectation and susceptibility results on Sections 5.3.4 and 5.3.5, the hydrodynamic processes represent a substantial control in the natural and perturbed evolution of the coastal geomorphology. Moreover, the articulation of the morphological units conceptualized for coastal environments may respond to various physiographic levels, such as the ones proposed in Italy, Australia and Puerto Rico for management plans of coastal zones at regional and national scale (Jackson, Bush, & Neal, 2009; Liguria, 2011; MATTM-Regioni, 2017; Montanari & Marasmi, 2014; Thom et al., 2018). Therefore, the compartment of littoral configurations within an environmental unit would providephysiographic integrity that modulates the susceptibility ranges of the SHIELP model. This may translate into some interventions changing from a lesser to a more restrictive licensing instrument, or vice versa, in particular, physiographic levels.

In order to introduce such improvements to the SHIELP model, several information gaps in Colombia need to be filled. These may include the estimation of the depth of closure at various return periods, the reach of the marine influence in coastal wetlands of large dimensions, a detailed cartographic representation of the sea floor at littoral areas, the distinction of the submerged hard strata or lithological and biogenic origin, and detailed surveys for recognizing offshore bars, stacks and similar features. In addition, the state of the art of several natural processes considered in the SHIELP model for coastal environments needs to be strengthen and improved, as mentioned in Chapter II, in order to enable precise predictions of geomorphological evolutions. Therefore, applied research on the natural processes influencing the coastal morphology is also pertinent in the EIA context as in the form of geoindicators.

As measures of the trend of geomorphological processes, the geoindicators have been conceived to track rapid geological changes, over periods of 100 years, which may contribute relevant information for environmental assessments (Berger, 2002, 2006; Rivas et al., 1997). Moreover, these kinds of indicators have already been used in coastal studies about risk assessment to property damage and similar characterization of hazards induced by natural conditions (Bush, Neal, Youbg, & Pilkey, 1999; Jackson et al., 2009). However, its potential application in the EIA context would cover the characterization of natural and human contribution to the geomorphological evolution, as well as the time and space spam of such responses of the natural systems to human-induced changes.

5.4.6. Changing approaches of EIA from the susceptibility concept

The comparison detailed in Chapter II, about the coastal context of the ELP within four countries, ratify Downs and Booth (2011)'s reflections about the need for re-conceptualizing management problems from a geomorphological perspective. As a tool for environmental management, EIA guidelines traditionally segment the environment into components, which forces geomorphology application within the constraints of traditional management practice (Pereira et al., 2018). Such strategy aims at minimizing the infringement of regulations through perceived risk and static morphology, instead of the achievement of environmental management goals (Downs & Booth, 2011). To overcome this, the proposed concept of susceptibility to the effect of human interventions attempts to shift the environmental management towards an approach more integrated with natural processes and landscape evolution, which harmonizes with the ecosystem services' conception (Enriquez-Acevedo, Botero, Cantero-Rodelo, Pertuz, & Suarez, 2018; Andrew Goudie, 2018).

In this novel strategy, the instruments for the environmental control (licensing) are customized by kinds of environments and, further in detail, by differentiated interactions of human interventions over morphological configurations. This susceptibility approach introduces a process-oriented analysis because the baseline characterization in the EIS is structured by the geomorphological processes influencing a distinctive kind of environment (e.g. the coastal zone). This approach overcomes the limitations stressed in Chapter II of the current fragmented-oriented analysis with generic environmental components (e.g. air quality, water quality or land use changes). Therefore, the SHIELP model here designed and demonstrated in a study area approximates to a truly successful application of geomorphology in addressing environmental management problems.

Additionally, the conceptual and methodological approach of the SHIELP model orbits around the morphological particularities of the location where a human intervention is projected, addressing in this way management purposes. The importance of place is one of the five fundamental dimensions of the environmental management, which seeks to benefit the human development by harmonizing and balancing anthropic interventions imposed on natural environments (A Goudie, 1994; O'Halloran, Green, Harley, Stanley, & Knill, 2004). Since such benefit may rely on the management objectives for a particular environment (Downs & Booth, 2011), a coherent institutional control should be framed by the distinctive kinds of environments (e.g. coastal, mountainous forest, continental wetlands, jungles, desserts…).

However, chapters II and IV reveal that the conventional ELP structure in Colombia, as in many other countries, organizes technical EIA guidelines and protocols around economic sectors and their pressing needs. In this sense, the SHIELP model contributes to another changing approach in the way environmental management is performed, by leading the assemblage of the licensing procedure toward distinctive kinds of environments instead of the type of interventions. With the articulation of this SHIELP approach in environmental regulatory frameworks, the distinctive environments in a territorial jurisdiction may have a better chance to achieve management goals. In this scenario, administrative protocols for the monitoring and control of environmental impacts are attached to a sound methodological framework that reduces subjectivity due to diverse regulatory interpretations.

5.5. Conclusions

A methodological approach has been developed to use the concept of susceptibility to the effect of human interventions to improve the Colombian ELP, called “SHIELP”. This model considers three variables (geomorphological processes, human interventions, and morphological configurations), which articulate three parameters about the geomorphological processes (affectation, importance, and perturbation), for their integration into one output (susceptibility of a morphological configuration to a human intervention). The application of the SHEILP model on coastal environments derived into a database of susceptibility and processes’ perturbation levels for the interaction of 52 probable interventions with 87 types of littoral configurations. Furthermore, the Colombian ECU Mag-Dique was used as a study area to demonstrate the operation of this susceptibility approach as a technical criterion for the screening and scoping stages of an ELP.

The application on coastal environments of the SHIELP model effectively describes the operation of an expert-diffuse system. The method to estimate the littoral susceptibility to the effect of human interventions proved suitable in situations in which knowledge about the relationship between variables, such as geomorphological processes, is incomplete and require an expert opinion on the issues. This methodological approach is a concrete example of how linguistic variables articulates with fuzzy logic principles to rate the predisposition of a landform to experience changes due to the human perturbation of geomorphological processes.

Furthermore, the research team of INVEMAR was a suitable source to articulate a technical instrument supporting the ELP in Colombia. They hold practical experience in recognizing the national coastal territory and alsothe role the official expert advisor for environmental authorities regarding coastal areas. Therefore, the research workshops at INVEMAR provided the expert opinion on process importance and interventions affectation for building and applying the SHIELP expert-diffuse system on coastal environments.

On the other hand, the scheme of littoral configurations defined for the SHIELP model for coastal environments represents the natural diversity of tropical coasts, such as the Colombian context. In addition, these approach describes coastal zones as a composition of distinctive emerged and submerged geomorphological units, instead of the classical view of subaerial features without their subaquatic projection. Nonetheless, this approach requires the fulfillment of information gaps about the Colombian littoral floors for improving the understanding of susceptibility to the effect of human interventions in coastal environments.

Finally, the methodological and conceptual approach of susceptibility to the effect of human interventions has been demonstrated as a technical criterion for improving environmental licensing. However, further improvements to the model can be elaborated, such as the criteria of inland boundary delimitation of the littoral configurations and transitional areas. In addition, to articulate the reach of the environmental management between these boundaries, a matrix of the interventions in transitional areas, that may induce a risk to the littoral zone, may be included as a complementary requirement in the terms of reference for impact assessments. This would ascertain the identification of possible terrestrial factors (inland) that may affect the coastal zone under assessment. In the main, future researches may address these improvement proposals through the analysis of the influence area of coastal interventions in the EIA context, with the aim of improving the criteria for boundary definitions.

Similarly, further developments should complement the susceptibility approach with other processes not addressed by the Earth sciences, because the SHIELP model is solely based on geomorphological processes. For instance, the mechanisms through which matter and energy flow within trophic webs are mastered by the sciences of living things. Equally, further anthropogenic process (e.g. cultural, economic fluxes or population dynamic) are better addressed by geographical and human sciences. This complementing approaches should cover all the spheres of environmental management for proper implementation of the susceptibility approach in the licensing procedures.

OVERALL CONCLUSIONS

Natural sciences have broadly developed during centuries because experiments can be conducted in controlled situations or settings. This ***is a challenge in the field of environmental sciences*** because few variables can be actually controlled and serious implications may derive from any feedback in real-world tests. Nevertheless, scientific research in environmental sciences is of paramount importance in order ***to articulate pathways of knowledge transfer from science to the real world***. The research here presented is an example of such challenging and yet necessary endeavor, where ***the knowledge on Earth Sciences are transferred to the needs of environmental management through the principles of impact assessment.*** Generalized principles of coastal functioning and evolution, through the enactment of geomorphological processes, are combined with novel reasoning of human impact through processes perturbation. This combination is consolidated as a definition of the physic-biotic susceptibility to the effect of human interventions. And such concept is particularly conceived to solve a problem in the real world: improve the deficiencies of environmental licensing procedures and environmental regulatory frameworks. Even though the study case and type of environment here exemplified fit the Colombian reality, there is a change of approach implicit in ***this research*** that ***may transcend the understanding of environmental impact assessments worldwide.*** This is, ***approaching the management of environmental impacts by the study of dynamic processes instead of static components***.

The present work encompasses the first comprehensive study of the human interventions with effect on the coastal zone at the regional scale of the entire continental Caribbean littoral of Colombia (over 1,700 km). Such analysis of coastal interventions and environmental management approaches addresses the hypothesis of this research, regarding the practice of the environmental licensing in the country. Thus, ***the environmental regulatory framework in Colombia has proven insufficient for managing the effect of human interventions in coastal environments due to*** identified weaknesses at early stages of the licensing procedure (Chapter II), its limited reach on the most relevant human interventions affecting the coastal zone (Chapter III) and its disarticulation with territorial planning instruments and policies (Chapter IV). All these situations have an underlying element in common, namely ***the unawareness of the natural susceptibility to the effect of human interventions***. From a geomorphological perspective, this susceptibility integrates the resilience of the natural system, as morphological configurations or landforms, with the intrinsic characteristics of the human intervention triggering changes in the landscape. In addition, such integration lies with the dynamic equilibrium described by the natural processes influencing the geomorphology of distinctive types of environments. And this articulation is described in the conceptual and methodological approach of susceptibility presented in Chapter V.

As stressed by Chapter II, some of the processes influencing the coastal morphology have limited scientific and technical knowledge regarding transformation rates and measurements. This would represent a limitation for shifting the management approach of environmental impacts, from the current fragmentation of the environment into static components toward the systemic analysis of dynamic processes. For implementing this novel approach in any environmental regulatory framework, specific data requirements need to be set. ***Future developments*** in this matter ***would imply the generation of technical guidelines about field data acquisition and modeling approaches that lead to the characterization of the natural processes influencing the landscape evolution*** of distinctive kinds of environments. Such technical criteria about the quantification of geomorphological processes would need to address different stages of the environmental licensing procedure: before the project's installation (characterization of the environment and impact prevision), during the project's operation (environmental monitoring or follow up) and after the project's decommissioning (environmental recovery or rehabilitation plan). Taking the example of some methodical referents introduced in Chapter II, these technical guidelines should describe the minimum lapse of observation, spatial coverage and suggested techniques for the quantification of the geomorphological processes.

According to Chapter III, the largest proportion of human works and activities with substantial effects on the dynamic equilibrium of coastal environments involve scattered human settlements, which are not explicit in the environmental regulatory framework of Colombia. In fact, these interventions currently lack procedural and normative support for monitoring their compliance with sustainable construction and operation measures, such as an environmental license. Such types of interventions may be considered negligible out of the context of the regional inventory conducted on the Colombian Caribbean Coast. However, recognizing how proliferous are these human developments and its derivative effects would call for a more articulated strategy. The compared results discussed in Chapter IV states that ***strict controls are worth applying on low-density settlements and hard shore protection structure, either by rigorous licensing instruments and/or by comprehensive territorial planning instruments***. Therefore, these small scale human developments need an improved environmental regulatory framework to limit admissible activities and/or minimum restrictive conditions to allow its implementation.

Even though most planning instruments in coastal municipalities are outdated, their structure should contain a clear definition of the areas of the urban expansion for the emplacement of low-density settlements. These types of human occupation are still under the regimen of uses and activities admitted in the national territorial instruments, namely land use plans (POT[2]), watershed management plans (POMCA[3]), and environmental plans for coastal zones (POMIUAC[4]). In addition, the particular case of luxury housing with piers is the kind of intervention that would require a positive concept from the maritime authority - DIMAR[5], because they occupy public domain according to the Decree-law 2324 of 1984. A big concern in this matter relies on the lightweight of the environmental pronouncement of competent authorities involved in permits and concessions. Therefore, the conceptual and methodological approach proposed in Chapter V addresses these technical and procedural flaws of the environmental regulatory framework of Colombia, by introducing the concept of susceptibility in the context of impact assessment. This scheme allows determining the necessary warnings to admit the development of certain uses and activities in certain areas that exhibit greater or lesser susceptibility to them, due to their natural characteristics. This is how the definition of ***susceptibility to the effect of human interventions*** arise as ***a novel approach to improve generic environmental licensing procedures and its articulation to territorial planning instruments***. Such conceptual and methodological proposal has been baptized as SHIELP: Susceptibility to Human Interventions for Environmental Licensing Purposes.

The study case on Chapter V, about the demonstration of the SHIELP model, also made evident how multiple institutions are generating the same type of information, while information gaps about the Colombian littorals remain partially unattended. The national geological service (SGC[6]), the national research institute of marine and coastal areas (INVEMAR[7]) and the research institute of the maritime authority (CIOH[8]) are each generating coastal geomorphological maps independently, which imply that national resources are being spent three times for the same product. Moreover, despite being governmental institutions, whose financing derive from public funds, there is still restricted access to the digital files of the data for the general public. On the other hand, several relevant information is still inexistent or unavailable from national official sources, especially regarding the submerged littoral configurations. Among the information gaps identified in this research are the official criteria for setting the submerged limits of the littoral zones, the lithological, sedimentological, biogenic and structural

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[2] In Spanish: Plan de Ordenamiento Territorial
[3] In Spanish: Plan de Ordenamiento y Manejo de una Cuenca
[4] In Spanish: Plan de Ordenamiento y Manejo Integrado de una Unidad Ambiental Costera
[5] In Spanish: Dirección General Marítima
[6] In Spanish: Servicio Geológico Colombiano
[7] In Spanish: Instituto de Investigaciones Marinas y Costeras "José Benito Vives De Andréis"
[8] In Spanish: Centro de Investigaciones Oceanográficas e Hidrográficas del Caribe

characterization of littoral bottoms, and the inventory of offshore bars. Furthermore, natural and human-induced processes influencing the coastal morphology need deepening on the techniques and instruments for characterizing the dynamic flux of matter and energy represented by them. Overall, ***an inter-institutional articulation is required to optimize the national resources in maintaining updated baseline information and generating the missing one to fill information gaps***. Particularly, mayor efforts need to be addressed to the determination of the lithological and structural characteristics of marine substrates (sub-bottoms), due to the complex geological configuration of the Caribbean, where active mud diapirism has already been responsible for nine knows victims.

The research here presented focuses on the coastal environment, but the SHIELP methodological approach can be widely applied to other distinctive environments on a given jurisdiction. For instance, in tropical countries as Colombia, the SHIELP model variables (natural processes, morphological configurations, and probable human interventions) can be further customized to the following kinds of environments: desserts, dry forests, valleys, piedmonts, mountains, plateaus, continental wetlands, wet jungles, and prairie, among others. Following the proposed methodology in Chapter V, the expert qualification of processes importance and affectation for customized parameters would have to be gathered and consolidated along with the fuzzy logic computation strategy. In making so, the ***SHIELP expert-diffuse system*** would be ***applied to*** a new kind of environment, other than the coastal zone. The resultant susceptibility databases for ***different kinds of environments can be articulated for a given territorial jurisdiction*** (e.g. country or region). In this way, the regulatory framework of the environmental licensing would ***successfully shift from*** structuring around types of interventions (***anthropocentric approach***) ***into*** orbiting the kinds of environments subject to pertinent monitoring and control (***ecosystem services approach***).

Some of the tropical environments aforementioned are already clustered in the five research institutes structuring the Colombian environmental system SINA[9]. For instance, the jurisdiction of the research institute SIMCHI[10] is the Amazon region, which may comprise continental wetlands, wet jungle, and prairies over its proximity to the Colombian eastern plains. Similarly, the jurisdiction of the research institute IIAP[11] is the Pacific region, with dense forests, valleys, and piedmont. Likewise, the jurisdiction of the research institute INVEMAR has been already established as the coastal

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[9] In Spanish: Sistema Nacional Ambiental

[10] In Spanish: Instituto Amazónico de Investigación Científica

[11] In Spanish: Instituto de Investigación Ambiental del Pacífico "John Von Neumann"

environments, both Pacific and Caribbean. At the same time, the institutes IDEAM[12] and HUMBOLDT[13] are somehow transversal in the physical and biologic dimensions, respectively. These last two institutions can be articulated with the other institutions, or they can specialize themselves on other distinctive environments (e.g. mountains, plateau and desserts). If each research center is empowered, both institutionally and financially, they can play a leading role in the ELP through the binding of their concepts in the decision making of regional and national environmental authorities. This would ease the articulation of an environmental licensing procedure by types of environments, instead of the current structure by economic sectors. In addition, the ruling decision in this novel approach would rest on the scientific arm of the environmental national system, instead of the economic and political interests.

Overall, this research work has documented the analysis of environmental regulatory schemes about licensing procedures in four countries. It has also highlighted generalized weaknesses on the conventional approaches for the management of environmental impacts in coastal environments. It has successfully demonstrated the need for a changing approach in the structure of environmental regulations and management of coastal environments, through a comprehensive inventory of human interventions at a gross regional scale. A geomorphological perspective has been translated into a technical criterion to improve the recurrent flaws of environmental licensing, at the early stages, through differentiated licensing instruments. All this has consolidated a conceptual and methodological approach of susceptibility, which relies on the understanding of the geomorphological processes configuring the landscape evolution. Even though this model has been applied and demonstrated on coastal environments and addressed the Colombian particularities, it comprises valid lessons and innovations for environmental impact assessments worldwide.

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[12] In Spanish: Instituto de Hidrología, Meteorología y Estudios Ambientales

[13] In Spanish: Instituto de Investigación de Recursos Biológicos "Alexander von Humboldt"

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