Co-production of indexes of beach management in the Catalan coast: A double-loop process of learning

Briana Angélica Bombana

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PhD Thesis | Briana Angélica Bombana

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PhD thesis developed by Briana Angélica Bombana
Supervised by Dr. Eduard Ariza Solé
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SUPERVISOR STATEMENT

I STATE that the present study, entitled "Co-production of indexes of beach management in the Catalan coast: A double-loop process of learning", presented by Briana Angélica Bombana for the award of the degree of Doctor, has been carried out under my supervision at the Department of Geography of this university.

Eduard Ariza Solé	Briana Angélica Bombana
Doctoral Thesis Supervisor	PhD Candidate

Bellaterra, September 19th 2019.

“Magda Lemonnier clips words out of the newspapers, words of all sizes, and she keeps them in boxes...

Sometimes she opens the boxes and upends them on the table, so the words can mix as they please. Then the words tell her what is happening and foretell what will occur”.

From the Spanish:

“*Magda Lemonnier recorta palabras de los diarios, palabras de todos los tamaños, y las guarda en cajas…*

A veces, ella abre las cajas y las pone boca abajo sobre la mesa, para que las palabras se mezclen como quieran. Entonces, las palabras le cuentan lo que ocurre y le anuncian lo que ocurrirá”.

Eduardo Galeano
Las palabras andantes (1993).

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La coproducció sobre la qual es centra aquesta tesi transcendeix les pàgines que la composen, i es refereix també (sinó principalment) al meu caminar com a doctoranda durant tot aquest procés. És a dir, sense la "comunitat de persones ampliada" amb la qual he tingut la sort de comptar en infinites ocasions, de maneres molt distintes, cadascuna amb la seva particularitat, jo no hagués pogut desenvolupar i acabar aquest treball. D'això, n'estic més que segura.

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A la disponibilitat, l'interès i l'atenció de totes les més de 70 persones que vau participar de les sessions plenàries, grups de discussió, entrevistes, enquestes i/o converses particulars sobre el tema d'aquesta tesi, les meves més sinceres gràcies. Aquest treball només existeix perquè hi heu estat aportant el vostre(s) gra(ns) de sorra a la meva comprensió de les platges catalanes. Espero que el producte final que veureu a continuació estigui a l'alçada de la vostra implicació.

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PRESENTATION

This thesis, entitled "Co-production of indexes of beach management in the Catalan coast: A double-loop process of learning", is part of the Doctoral Program in Geography at the Autonomous University of Barcelona (from the Catalan, *Universitat Autònoma de Barcelona* – UAB). The project has been developed within the research group SGR-Interfase of the Department of Geography of the mentioned University under the supervision of Dr. Eduard Ariza Solé. Throughout the four years of research, I had the support of the Brazilian Ministry of Education by a CAPES Fellowship (99999.001355/2015-05).

This document is structured following the rules for the presentation of doctoral theses by a compendium of publications, approved by the Academic Committee of the aforesaid Doctoral Program (from the Catalan, *Comitè Acadèmic del Programa de Doctorat* - CAP). It is regulated by RD 99/2011 according to the transitory disposition approved by the CAP on April 10th, 2015 for students enrolled prior to the 2015-2016 academic year.

According to the regulation RD 1393/2007 regarding the order of contents of this doctoral thesis, it is structured in three main sections:

1) Introduction and justification of the thematic unit
2) (Potential) Publications that are part of the compendium of the thesis
3) Global discussion of the final results and conclusions

In this context, two original scientific contributions (already published elsewhere) that follow the line of research on transdisciplinary analyses and tools for coastal zones are provided. The contributions have been approved by the corresponding CAP on July 17th, 2019; references are provided below detailing the respective scientific journals, the impact factor (FI) and the ranking of the Journal Citation Report® of Thomson Reuters (JCR) and the SCOPUS® of Elsevier (SJR). It is important to note, nonetheless, that the final content of this thesis also includes a third contribution that, although it has not yet been published, is designed to be submitted as a research article to a scientific journal as soon as possible.

Compendium of publications

PUBLICATION 1 (Article)

Bombana, B & Ariza, E. (2018). **Clarifying some assumptions of coastal management: Analysis of values and uncertainties embedded in beach quality indexes.** Ecological Indicators, 91, 376-385.
DOI: https://doi.org/10.1016/j.ecolind.2018.03.066

JCR Impact Factor (2018): 4.490.
- 45/250 (Q1) in Environmental Sciences.

SJR Impact Factor (2018): 1.352.
- Q1 in Decision Sciences.
- Q1 in Ecology.
- Q1 in Ecology, Evolution, Behavior and Systematics.
- H Index 97.

PUBLICATION 2 (Article)
Bombana, B & Ariza, E. (2019). **A double-loop process for beach quality index construction: Approaching the complexity of the Catalan coast.** Journal of Environmental Management, 240, 177-189.
DOI: https://doi.org/10.1016/j.jenvman.2019.03.100

JCR Impact Factor (2018): 4.865.
- 37/250 (Q1) in Environmental Sciences.

SJR Impact Factor (2018): 1.21.
- Q1 in Environmental Engineering.
- Q1 in Management, Monitoring, Policy and Law.
- H Index 146.

Besides the publications composing this thesis (the two already referenced and the third potential publication), other outcomes originated from its development, i.e. two conference papers, one international research stay, four contributions to conferences, and teaching of classes. All of them are briefly outlined in the following paragraphs.

Other publications originated from the present thesis

Bombana, B & Ariza, E. (2017). ***Evaluación de la calidad de las playas: Principales debilidades*.** Conference paper. Acta XXV *Congreso de la Asociación Española de Geografía* (AGE).

Bombana, B; Solé Figueras, L & Souza, R. (2016). ***Comparación de las decisiones que afectan al territorio y a las dunas costeras en la Bahía de Roses: Una aproximación desde la Ciencia Posnormal.*** Conference paper. Acta *Simposium de Jóvenes Investigadores en Geografía* (SIJIG 2016).

Research stay

Florida International University (United States of America)
Department of Earth and Environment
Research stay supervisor: Dr. Pallab Mozumder
Duration: 90 days (March – June 2017)

Conferences

II *Congresso Ibero Americano de Gestão Integrada de Áreas Litorais* (II GIAL)

Bombana, B & Ariza, E. (2016). *Análisis del sistema socio-ecológico playa desde la ciencia Posnormal: Asunciones e incertidumbres vinculadas a su gestión*. Oral presentation. Florianópolis, Brazil.

***Simposium de Jóvenes Investigadores en Geografía* (SIJIG 2016)**

Bombana, B; Solé Figueras, L & Souza, R. (2016). *Comparación de las decisiones que afectan al territorio y a las dunas costeras en la Bahía de Roses: Una aproximación desde la Ciencia Posnormal*. Oral presentation. Barcelona, Spain.

XXV *Congreso de la Asociación Española de Geografía (AGE)*

Bombana, B & Ariza, E. (2017). *Evaluación de la calidad de las playas: Principales debilidades*. Oral presentation. Madrid, Spain.

4th Post-normal Science (PNS) Symposium

Bombana, B & Ariza, E. (2018). A double-loop process for beach quality indexes: Addressing the complexity of Catalan coast. Oral presentation. Barcelona, Spain.

Classes

Coastal socioecological systems: The case of the Catalan beaches

Coastal Geography subject of the Undergraduate studies in Geography and Territorial Planning and of the Undergraduate studies in Environmental Sciences at the Autonomous University of Barcelona. (Amount of hours: 3h).

Coastal socioecological systems: The analysis of the Catalan beaches

Geography of Catalonia subject of the Undergraduate studies in Geography and Territorial Planning at the Autonomous University of Barcelona. (Amount of hours: 3h).

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ABSTRACT

The modern world context challenges the scientific endeavour to uncritically accept simplifications (e.g. indexes) to aid in understanding complex problems. More than the search for “true” assessments, complexity imposes the need for quality in the procedural form of acquiring knowledge, grounded in an advanced awareness of the context in which research is embedded and carried out. The present thesis aimed at the co-production of indexes for the beach management of Catalan beaches based on expanded peer processes within a wide double-loop (DL) process of learning. Here, the phases of selection, definition and production of indexes, and the reporting of information for policy were based on feedback from a plethora of (types of) stakeholders. This feedback questioned underlying values, emphasized arguments behind choices and integrated learning from past efforts in the field of beach management. The Catalan beaches, located in the north-western Mediterranean (Spain), were selected as a case study because of the registered array of multi-dimensional conflicts (e.g. tourism massification, depletion of natural heritage, etc.), assets and processes; its international importance as a sea-and-sand touristic destination; its insertion in a regional management scale; and the wealth of existing academic studies. Despite that, before this work was developed, no assessment of the information available in the science-policy interface about this coastal territory had been carried out. Hence, I began by opening the Beach Quality Index (BQI) to criticism through an expanded peer community. The BQI was created by an interdisciplinary team of coastal scientists in 2010 and was designed to cater to and assess beaches as socio-ecological systems. In this process, 108 direct participations by stakeholders were included throughout two multi-stakeholder meetings, five focus groups and complementary surveys, interviews and informal contacts. Four main narratives explaining the Catalan beach systems and defining management objectives were identified and guided the whole research – economic growth, sustainable development, environmental protection and integrated coastal zone management. The analysis of the BQI structure and the embedded values and uncertainties showed it to be somewhat robust, especially regarding a low influence of resource limitations and a satisfying agreement among peers and objectivity of the analysts. However, dissociation between the discourse and the operational development of this tool was observed, as well as a prioritisation of user satisfaction (economic growth narrative) and recurrent decontextualised scientific data. The co-production of a new updated tool – the Double-Looped BQI (DL-BQI) – was developed to account for the aforesaid limitations by changing how some processes were being observed and adding new observable assets (what to observe), e.g. natural heritage, to improve the pertinence and usefulness of the knowledge produced. After that, the DL-BQI was applied and peer-reviewed in 96 beaches of Catalonia and the results obtained were reported for policy. Generally, except for some beach types and locations, the beach management endured in Catalonia has conditioned these systems to the development of tourism and leisure and has also leaned toward the economic growth narrative. This orientation, together with a few considerations of the sustainable development and environmental protection narratives, has mainly explained the observed negative pressures and corresponding impacts in ecological assets and natural heritage. Economic growth, predominant in both the SL-BQI and in the outcomes of beach management, showed to be obsolete for tackling complex problems and achieving sustainability. Emphasising the value of beaches as natural systems, as in other narratives, would potentially promote plausible alternatives to the current status. The co-production process has been shown to be capable of comprising the constant changes, different dimensions and context of the Catalan coast in the DL-BQI, test it, and thus report higher quality information for policy.

Keywords: Complexity, post-normal science, co-production, knowledge assessment, indicators, double-loop process of learning, beach management, Catalonia.

RESUM

El context actual és un desafiament a l'esforç científic d'acceptar de forma acrítica les simplificacions (per exemple, els índexs) per a la comprensió dels problemes complexos. Més que la "veritat" en les avaluacions, la complexitat exigeix una certa qualitat del procediment utilitzat per adquirir coneixements, fonamentada en una consciència avançada del context en el qual s'inclou i es desenvolupa la recerca. Aquesta tesi té com a objectiu la coproducció d'índexs per a la gestió de platges de Catalunya basats en processos de parells ampliats dins d'un ampli procés d'aprenentatge de doble cicle (DL). La selecció, definició i producció d'índexs i el seu informe per a la política s'han basat en comentaris d'una plètora de *stakeholders*, que van qüestionar i emfatitzar els valors subjacents, els arguments darrere de les eleccions i l'aprenentatge bastit anteriorment en l'àmbit de la gestió de platges. Les platges catalanes (Mediterrani nord-oest, Espanya) van ser seleccionades com a cas d'estudi a causa de la presència de conflictes (massificació turística, esgotament del patrimoni natural, etc.), elements i processos multidimensionals; una importància internacional com a destinació turística; la seva correspondència a una escala de gestió regional; i, la riquesa dels estudis acadèmics existents. Malgrat això, abans del present treball, no s'havia fet cap avaluació del coneixement disponible sobre aquest territori costaner a la interfície ciència-política. Per tant, vaig començar la recerca mitjançant una revisió crítica de l'índex de qualitat de platja (BQI), a través d'una comunitat de parells ampliada. El BQI va ser creat per un equip interdisciplinari de científics el 2010 per a valorar les platges com a sistemes socioecològics. Durant aquesta tesi i mitjançant dues reunions participatives, cinc grups focals, enquestes complementàries, entrevistes i contactes informals, 108 participacions directes van identificar quatre narratives principals - creixement econòmic, desenvolupament sostenible, protecció ambiental i gestió integrada costanera - que van explicar les platges catalanes, definir els objectius de gestió i guiar tota la recerca. L'anàlisi de l'estructura, valors i incerteses del BQI va mostrar que aquesta eina és prou robusta, sobretot degut a una baixa influència de les limitacions de recursos i un acord satisfactori entre els parells i l'objectivitat dels analistes. Tot i això, es va observar una dissociació entre el discurs i el desenvolupament operatiu d'aquesta eina, així com una priorització de la satisfacció dels usuaris (narrativa de creixement econòmic) i dades científiques descontextualitzades. La coproducció d'una nova eina actualitzada - el Doble-cicle BQI (DL-BQI) - va permetre considerar les limitacions esmentades, canviant la manera com alguns processos estaven sent observats i afegint-hi nous elements, per millorar la pertinència i la utilitat del coneixement produït. Després, es va aplicar i revisar el DL-BQI a 96 platges de Catalunya i els resultats obtinguts s'han enfocat a la gestió pública de les platges. Generalment, excepte per alguns tipus i localitats de platges, la gestió realitzada a Catalunya ha condicionat les seves platges al desenvolupament del turisme i l'oci (narrativa del creixement econòmic). Aquesta orientació, juntament amb una feble consideració de les narratives de desenvolupament sostenible i protecció ambiental, han explicat principalment les pressions negatives observades i els impactes corresponents en la majoria dels béns ecològics i el patrimoni natural costaner. El creixement econòmic, predominant tant en el SL-BQI com en els resultats de la gestió esmentada, es va mostrar, doncs, obsolet per afrontar els problemes complexos actuals. L'èmfasi en les platges com a sistemes

naturals, d'acord amb altres narratives, ajudaria a potenciar alternatives a l'estat actual. El procés de coproducció ha demostrat ser capaç d'incloure en el DL-BQI els canvis constants, les diferents dimensions i el context de la costa catalana, de testar-lo i, finalment, aportar amb informació de més qualitat per a la política pública.

Paraules clau: complexitat, ciència posnormal, coproducció, avaluació del coneixement, indicadors, procés d'aprenentatge de doble bucle, gestió de platges, Catalunya.

RESUMEN

El contexto global actual supone un desafío para el esfuerzo científico de aceptar de forma acrítica las simplificaciones (por ejemplo, los índices) para la comprensión de los problemas complejos. Más que la "verdad" en las evaluaciones, la complejidad exige una cierta calidad del procedimiento utilizado para adquirir conocimientos, basada en una conciencia avanzada del contexto en el cual se incluye y se desarrolla la investigación. Esta tesis tuvo como objetivo la coproducción de índices para la gestión de playas de Cataluña basados en procesos de pares ampliados dentro de un amplio aprendizaje de doble bucle (DL). La selección, definición y producción de índices y su informe para la política se basaron en comentarios de una plétora de *stakeholders*, que cuestionaron y enfatizaron los valores subyacentes, los argumentos detrás de las elecciones y el aprendizaje construido anteriormente en el ámbito de la gestión de playas. Las playas catalanas (Mediterráneo noroeste, España) fueron seleccionadas como caso de estudio debido a la presencia de conflictos (masificación turística, agotamiento del patrimonio natural, etc.), elementos y procesos multidimensionales; una importancia internacional como destino turístico; su correspondencia a una escala de gestión regional; y, la riqueza de los estudios académicos existentes. Sin embargo, antes del presente trabajo, no se había realizado ninguna evaluación del conocimiento disponible sobre este territorio costero en la interfaz ciencia-política. Por lo tanto, empecé por realizar una revisión crítica sobre el índice de calidad de playa (BQI), a través de una comunidad de pares ampliada. El BQI fue creado por un equipo interdisciplinario de científicos en 2010 para valorar las playas como sistemas socioecológicos. Durante esta tesis y mediante dos reuniones participativas, cinco grupos focales, encuestas complementarias, entrevistas y contactos informales, 108 participaciones directas identificaron cuatro narrativas principales - crecimiento económico, desarrollo sostenible, protección ambiental y gestión integrada costera - que explicaron las playas catalanas, definieron los objetivos de gestión y guiaron toda la investigación. El análisis de la estructura, valores e incertidumbres del BQI mostró que esta herramienta es bastante robusta, sobre todo debido a una baja influencia de las limitaciones de recursos y un acuerdo satisfactorio entre los pares y la objetividad de los analistas. Sin embargo, se observó una disociación entre el discurso y el desarrollo operativo de esta herramienta, así como una priorización de la satisfacción de los usuarios (narrativa de crecimiento económico) y datos científicos descontextualizados. La coproducción de una nueva herramienta actualizada - el Doble-bucle BQI (DL-BQI) – permitió incluir las limitaciones mencionadas, cambiando la forma de observación de algunos procesos y añadiendo nuevos elementos, para mejorar la pertinencia y la utilidad del conocimiento producido. Después, se aplicó y revisó el DL-BQI a 96 playas de Cataluña y los resultados obtenidos se han enfocado a la gestión pública de las playas. Generalmente, excepto para algunos tipos y localidades de playas, la gestión realizada en Cataluña ha condicionado sus playas al desarrollo del turismo y el ocio (narrativa del crecimiento económico). Esta orientación, junto con una débil consideración de las narrativas de desarrollo sostenible y protección ambiental, han explicado principalmente las presiones negativas observadas y los impactos correspondientes en la mayoría de los bienes ecológicos y el patrimonio natural costero. El crecimiento económico, predominante

tanto en el SL-BQI como en los resultados de dicha gestión, se mostró, por tanto, obsoleto para afrontar los problemas complejos actuales. El énfasis en las playas como sistemas naturales, de acuerdo con otras narrativas, ayudaría a potenciar alternativas al estado actual. El proceso de coproducción demostró ser capaz de incluir en el DL-BQI los cambios constantes, las diferentes dimensiones y el contexto de la costa catalana, de testarlo y, finalmente, aportar con información de más calidad para la política pública.

Palabras clave: Complejidad, ciencia posnormal, coproducción, evaluación del conocimiento, indicadores, proceso de aprendizaje de doble bucle, gestión de playas, Cataluña.

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LIST OF ABBREVIATIONS

1D One dimension
3D Three dimensions
AC Autonomous community
ACA Catalan Water Agency (From the Catalan, *Agència Catalana de l'Aigua*)
AEMET State Meteorological Agency (From the Spanish, *Agencia Estatal de Meteorología*)
BOE Official State Gazette (From the Spanish, *Boletín Oficial del Estado*)
BEI Beach Evaluation Index
BHI Beach Health Index
BQI Beach Quality Index
BS Beach systems
CARLIT Cartography of littoral and upper-sublittoral rocky-shore communities
CV Contingent Valuation
CFU Colony-Forming Unit
CIIRC International Centre for Coastal Resources Research (From the Catalan, *Centre Internacional d'Investigació dels Recursos Costaners*)
DL Double-loop
DL-BQI Double-looped Beach Quality Index
E Ecological
EBMS Ecosystem-Based Management System
EC European Commission
EF Ecological Footprint
EG Economic Growth
EMS Environmental Management Systems
EP Environmental Protection
EPA Expanded peer assessment
EC European Commission
EQR Ecological Quality Ratio
EU European Union
FAN Phosphates – Ammonia - Nitrites (From the Catalan, *Fosfats – Amoníac - Nitrits*)
FG(s) Focus Group(s)
Gencat Government of Catalonia (From the Catalan, *Generalitat de Catalunya*)
GESAMP Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS Geographic Information Systems
ha hectare
HP Hedonic Prices
IBVI Integrated Beach Evaluation Index
IC Interest in Conserving
ICAPTU Index of Environmental Quality in Tourist Beaches (From the Spanish, *Índex de Calidad Ambiental de Playas Turísticas*)
ICZM Integrated Coastal Zone Management
l (L in lower case) liter
LC (Spanish abbreviation) *Ley de Costas*

m (M in lower case) meter
MEDOCC (Catalan abbreviation) *Macro-invertebrats MEDiterrània OCCidental*
MS-meeting(s) Multi-stakeholder meeting(s)
MTPD Maritime-terrestrial public domain
NB Natural beaches
NUSAP Numeral Unity Spread Assessment Pedigree
PA System Public Address System
PC Physical-chemical
PDUSC Development Plan for the Coastal System of Catalonia (From the Catalan, *Plan Director Urbanistic del Sistema Costaner*)
PEIN Plan for Areas of Natural Interest (From the Catalan, *Pla d'espais d'interès natural*)
PNS Post-Normal Science
POMI *Posidonia oceanica* Multivariate Index
SbI(s) Set(s) of sub-indexes
SD Sustainable Development
SES Socioecological systems
SL Single-loop
SL-BQI Single-looped Beach Quality Index
SUB Semi-urban beaches
TCM Travel cost method
UB Urban beaches
UN United Nations
UNEP United Nations Environment Programme
µmol Micromole
µg Microgram

1. INTRODUCTION

1. FRAMEWORK

The theoretical framework behind the development of this dissertation is briefly approached in the following sections. Given that I understand beaches and corresponding problems as having complexity as an inherent property, I advance on this topic by giving some notions about its epistemology. After this, I introduce post-normal science (PNS), which is a new paradigm through which complexity can be integrated in scientific studies, followed by its potential contribution to sustainability and transdisciplinary studies, and vice versa. Finally, by looking at the co-production of beach indexes, I augment the present theoretic contextualization by expounding upon the gap between indexes and narratives.

1.1. Epistemology of complexity

> In Science … "we looked for global schemes, symmetries, immutable general laws and we have discovered the mutable, the temporary, the complex". Prigorine (1983, p. 24), translated from the Spanish.

The capacity to academically study complex systems has been developed since the mid- 1950s (Simon, 1962; Bertalanffy, 1968), in part, following inspiration from eastern religions and philosophies (Wright, et al., 2019). Socio-ecological systems (SES), understood within a framework where human and natural systems are coupled, is one meaningful example of such complex systems, given that they are inherently impermanent and deploy interscale processes, reciprocal feedback loops between diverse organizational units, time lags, resilience, and heterogeneousness (Liu, et al., 2007). The socio-natural contains essential elements of randomness and irreversibility, associated with spontaneous activity, whilst the artificial may be deterministic and reversible (Prigorine, 1983).

In this context, studies that aim to simulate SES through scientific models have displayed many shortcomings originating from the embedded characteristics of ecological problems, i.e. non-reducibility, spatial and temporal variability, uncertainty, collectivity, and spontaneity (Dryzek, 1987); such shortcomings make it difficult to translate systems into a legible language and to predict their behaviour from this potential simplified translation. In other words, SES display complexity as a property (Funtowicz, et al., 1999), unfolding a plethora of multidirectional relations and nonlinear dynamic changes in time and space (Wright, et al., 2019). Allen et al. (2017) characterized these modelling shortcomings as being the main distinction between complex and simple or complicated systems.

The advent of systemic perspectives came to challenge the assumption that a common linear and simplified rationale could be sufficient to describe, analyse, and control SES; instead, the science–policy interface needs complex thought to understand our complex world (Max-Neef, 2005). The modelling of complex systems, in fact, may manifest at least two non-reducible causes of uncertainty[1]: The first refers to their condition as “becoming systems” (Prigorine, 1983), which limits any measurement model to an expiration date given their lack of capacity, if not updated, to observe the natural evolutionary embedded changes. The second is their unfeasibility to represent all hierarchical levels and corresponding scales into a single set of measurements (Simon, 1962; Giampietro, et al., 2006; Garnåsjordet, et al., 2012).

Regardless of external material implications of complexity, treating SES only in terms of materiality could result in the loss of information in the process of making these systems’ units become parts of a scheme of interpretation. Approaching the SES from the complexity epistemology, however, could warrant a means to advance further in the understanding of such systems (Allen, et al., 2017). To cite an example, a beach does not scheme about interacting waves and sand in order to maintain itself; instead, complexity arises when an observer attempting to understand beach behaviour starts to search for explanations in the interaction between water and land. In this work, thus, we take the assertion of Allen, et al. (2017) as a guide, highlighting that complexity is “more conceptual and less physical” than we are used to thinking.

In SES, complexity is manifested through “wicked problems” due to dissimilar human values and deep uncertainty within a system and its present and future dynamics (Rittel & Webber, 1973), making it impossible to identify, assess, and tackle these problems using a single agreed-upon perspective (Allenby & Sarewitz, 2011). Dissimilar human values recall the infinite set of potential descriptions of the system—epistemological plurality from non-equivalent observers—that unfolds on deep uncertainty together with the infinite possibilities for observing these being and becoming systems—ontological plurality from non-equivalent observations (Munda, 2004). These considerations on wicked problems—the existence of high uncertainties and values in dispute—when added to high stakes and urgency in decision making, bring us to the introduction of a PNS as an alternative to approach complexity in the science–policy interface.

1.2. Integrating complexity through the post-normal science (PNS)

In the mid-1980s, Funtowicz and Ravetz (1992; 1993) proposed the PNS framework (Kønig, et al., 2017), given that the classical linear methodology of the widespread traditional strategies of science—i.e. basic and applied (laboratory) science, and professional consultancy—could not properly answer current complex conflicts. A myriad of contemporary unsolved problems[2] corroborates that such strategies have not displayed, at least so far, a true capacity for aiding decisions: climate emergency, environmental damage, shortage of resources, terrorism, management of genetically modified organisms, and so on (Giampietro, 2015; Sarewitz, 2004). Within a context of indeterminacy, conventional science itself has been said to be a source of uncertainty, especially if information for policy is delivered without context and proper recognition

[1] From now on, taken as “any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system” (Walker, et al., 2003, p. 5).

[2] Here understood as inconsistencies across an expected and perceived state of matters (Giampietro, 2015).

of shortcomings (Refsgaard et al., 2006 in Kovacic, 2015; Funtowicz & Ravetz, 1992; Maxim & Van der Sluijs, 2011).

The plethora of uncertainties, high values in dispute, and urgent decisions at stake have made PNS scholars advocate for evidencing these characteristics of complex current problems, moving them to the centre of scientific analyses (Funtowicz & Ravetz, 1993). As in any other paradigm in science, PNS includes expressed theory reflecting the characteristics of current problems and how science should approach them (i.e. complex problems unfolding different types of uncertainties, which should be treated through the lenses of an expanded peer[3] community) and empirical research (e.g. application of expanded peer reviews to qualitatively assess uncertainty and the subsequent outcomes) that look at providing insights into complexity (Martin, 2015). The most prominent distinction between the PNS approach and classical, "normal" science (Khun, 1962) is that whereas classical science poses knowledge as the aim and quality as certainty, the approach advocated here aims at quality as the goal (Kønig, et al., 2017).

Above all, the urgency of decisions makes the idea of quality assurance central for delivering quick but trustworthy scientific information (Walker, et al., 2003). This calls for an expansion of the traditional analyses of parameter uncertainties to produce relevant outcomes (Van der Sluijs, et al., 2003). Uncertainties are varied and may hold different dimensions: 1) location—where it manifests itself in a scientific analysis, 2) level—where it manifests itself in a range between total ignorance and deterministic knowledge, and 3) nature—depending on whether it originates because of imperfect scientific knowledge or the variability of the object of scientific inquiry (Walker, et al., 2003). Traditional quality assessments, however, have been usually tried to quantify those uncertainties of statistical and scenario nature (i.e. the ones closer to having the capacity for deterministic knowledge) but have poorly addressed the possible lack of relevance of science for policy (Maxim & Van der Sluijs, 2011). Departing from the point that political, social, and economic characteristics also influence scientific processes, qualitative assessments of uncertainty which look at the negotiations between stakeholders should also be included in a quality assurance process (Maxim & Van der Sluijs, 2011).

Under current circumstances, quality should be about how something has been built (focusing on the process) and not only about that something being true (focusing on the final outcome), so that it addresses technical and methodological shortcomings, but also epistemological and ontological challenges (Funtowicz & Ravetz, 1990). In this study, quality of knowledge is taken as both a fundamental concept that must be achieved (e.g. in knowledge products) and a process throughout the "awareness of research context, explicitness and clear justification of the adequacy of the research properties with respect to the research objectives and appreciation for the

[3] In this work, the terms "peers", "parts", and "stakeholders" are treated as the same concept, i.e. "those interested, involved or affected by coastal/beach management process or particular actions, and … seen in [the] form of organizations, groups or individuals" (Pomeroy & Douvere, 2008).

interpretative context within which the research results would be applied" (Dell'Angelo, 2013, p. 26).

Within the political use of science, Van der Sluijs and collaborators (2010) defined three strategies to deal with uncertainty: 1) building of scientific consensus, 2) quantification of uncertainty, and 3) openness about ignorance. In particular, new research methods aiming to produce more trustworthy, quality information for policy have operationalized the aforementioned PNS elements through a model of extended participation (i.e. openness) in which science is not a unitary activity (Kovacic, 2015). That is, if quality is constrained by a sincere and open debate among people affected by the problem in question, an "extended peer community" would be formed by traditional institutions as well as other groups of people aiming at contributing to its resolution (Ravetz, 1999). It is believed that extending the peer community is central to enhancing the decision-making process on complex systems and should be made, as soon as possible, a part of political and scientific agendas (Munda, 2004).

From its beginnings until now, PNS has gained much terrain in diverse fields, approaching current problems (e.g. climate change, risk management, technology developments, etc.) through both descriptive and normative advancements, and sharing these advancements in new ways besides publications (e.g. the first PNS symposium on "Post-Normal Science in Practice" in 2014) (Dankel, et al., 2017). Though the change has happened slowly, some policymakers and advisors have started to perceive PNS as convenient rather than a handicap, probably because of, amongst other things, its capacity and flexibility to offer different transparent, reflexive, and democratic strategies to current complex problems (Dankel, et al., 2017). Despite the theoretical and practical examples of its application, it is noteworthy that only a few studies have focused on applying PNS in practice at the scale of regional and national territories (e.g. Swedeen, 2006; Petersen, et al., 2010).

1.3. Sustainability and transdisciplinarity

Sustainability is a concept introduced within the framework of the Brundtland Commission Report (Brundtland, 1987) that called for sustainable development (SD), through which the world could meet the "basic needs of all and extending to all (including future generations) the opportunity to satisfy their aspirations for a better life". SD was based on the assumption of an existing dynamism and interconnectedness among social, economic, and environmental open systems, and deploying transgenerational social equity, economic prosperity, and environmental health as its main goals (Shields, et al., 2002). By combining developmentalist and environmentalist projects in an umbrella conceptualization, it has received wide acceptance and is, nowadays, frequently referenced by political figures, entrepreneurs, scientists, journalists, NGOs, etc. (Nilsen, 2009; Boda & Faran, 2018). Part of its popularity is justified as well as problematized by the embedded vagueness, ambiguity (Manderson, 2006), and slowness in proposing solutions to urgent global problems (e.g. world poverty, climate change, and sea level rise) (Dahl, 2012).

Over the past 30 years, sustainability has evolved to embrace emerging environmental problems and has started to unfold into non-exclusive classifications; the paradigm of

SD in itself is an example of such classifications (Boda & Faran, 2018). Following this evolution, I should specifically highlight the concepts of weak and strong sustainability, which defend, respectively, the maintenance of total capital even if, by doing so, natural capital is substituted by manufactured capital; and the idea that natural systems cannot (at least, partially) be reduced to capital (Gudynas, 2000; Nilsen, 2009; Boda & Faran, 2018). In parallel, instrumental sustainability ait is nrose as a way to achieve economic benefits or reduce economic costs by addressing some sustainable challenges demanded by the public. Conversely, deep sustainability aims at tackling the root foundations of unsustainability (e.g. ethical, philosophical, and spiritual domains) (Ikerd, et al., 2014). It is noteworthy that strong and deep sustainability implies digging further into socio-ecological relationships that, when the role of weak and instrumental sustainability in providing some alternatives to current problems is not denied, demands other new forms of perceiving and debating the embedded challenges.

In the framework of complex systems, for the purpose of the present research I selected the definition of sustainability proposed by Manderson (2006, p.92) as the "changing ability of one or many systems to sustain the changing requirements of one or many systems, over time". This author also posed a note on the likewise encompassed ambiguity of this interpretation, calling attention to the possibility of mapping some of the complexity (e.g. what is being sustained, and how) but not its entirety because of the changing dynamics. The mapping of complexity for sustainability, thus, will hinge on a set of different economic, ecological, and social disciplines which debate the different systems and the connections among them, emphasizing the importance of interdisciplinarity (Boda & Faran, 2018).

The increasing number of disciplines and access to education in recent decades, nevertheless, did not curb the increase of complex environmental problems contributing to an unsustainable future; rather, the opposite occurred, so that discussions about transformative and transformational education for a deeper understanding of things have started to receive attention (Sterling, 2010). This argues for a movement towards restructuring the basic precepts, feelings, and actions of thought in order to change consciousness (Sterling, 2010) on sustainability. Transdisciplinary here emerged as a path for reflexive research, in which an interdisciplinary teamwork and collaboration between researchers and non-academic actors are encouraged, allowing processes of mutual learning across science and society (Jahn, et al., 2012). This has been conceptualized as "the transgression of disciplinary boundaries" beyond multidisciplinarity, pluridisciplinarity, and interdisciplinarity (Nicolescu, 2002). To establish links between bodies of knowledge, three main phases of this path are needed: 1) problem formulation, 2) production of knowledge, and 3) evaluation of the new knowledge based on transdisciplinary integration (Jahn, et al., 2012).

Max-Neef (2005) exposed an essentially practical transdisciplinarity in which classical methods and rationales could be applied through potential multiple relations among four levels of organization: 1) empirical (what exists), 2) pragmatic (what we are capable of doing), 3) normative (what we want to do), and 4) values (what we must do). However, going beyond the traditional reasoning of academic institutions and operating through multiple levels of reality for understanding complexity is what would make for a strong transdisciplinarity, enabling us to see the world in a more systemic and holistic way.

1.4. The gap between narratives and indexes[4]

Indexes have been developed in diverse academic fields for the measurement of the relevant socio-ecological processes. These have tried to approach complex systems through the simplification of their components and relations, from a planetary scale, as the Ecological Footprint (Global Footprint Network, n.d.); through the national scale, e.g. the UN Sustainable Development Goals Index (United Nations, 2019); to regional and local scales, e.g. the Spanish municipal system of urban and local sustainability indexes (Ministerio de Fomento, 2010) or the Beach Quality Index (Ariza et al., 2010; explained hereinafter).

Simplification, necessary to represent a complex issue especially because having a representation so detailed as the issue would be useless for policy, has relied on quantitative analyses and objective outcomes—usually, numbers—which give an idea of trustworthy information, being attractive and widely used by scientists and statistics offices (Pereira & Funtowicz, 2015; Kovacic, 2015). Nonetheless, numbers have also been demonstrated to be vague, ambiguous (Kovacic, 2015), and obviate irreducible uncertainties, representing scientific assumptions and different potential outcomes (Pereira & Funtowicz, 2015). For example, the concept of Ecological Footprint (EF) is criticized because the evaluation of the deficit of (virtual) land on the planet is estimated through the carbon footprint of energy production, ignoring assumptions and simplifications that are not being reported in the resulting EF number (Giampietro & Saltelli, 2014).

Simon (1962) believed, however, that we could achieve an adequate simplification if we were able to find the right representation of complex systems. I here defend that such a representation can assume different adaptive forms given that it is primarily a matter of perception, which changes through time, mainly due to the constant changes of these systems and the reciprocal interaction between them and observers. Giampietro et al. (2006) introduced Rosen's modelling relation (1985), in which a perception of a natural observed system (e.g. a beach) should be represented in a formal system (e.g. an index) by the procedures of encoding relevant attributes of the system into proxy variables, of inferring the links between variables and processes ruling them, and of decoding the values obtained from the proxy variables in order to analyse the state of the socio-ecological system (Figure 1).

[4] In the following, the term "index", taken as a synonym for the term "indicator", is applied as in Inhaber (1976) (in Alberti & Parker, 1991, p. 97): "the comparison of a quantity to a scientific or arbitrary standards", independent from weighting and aggregation procedures.

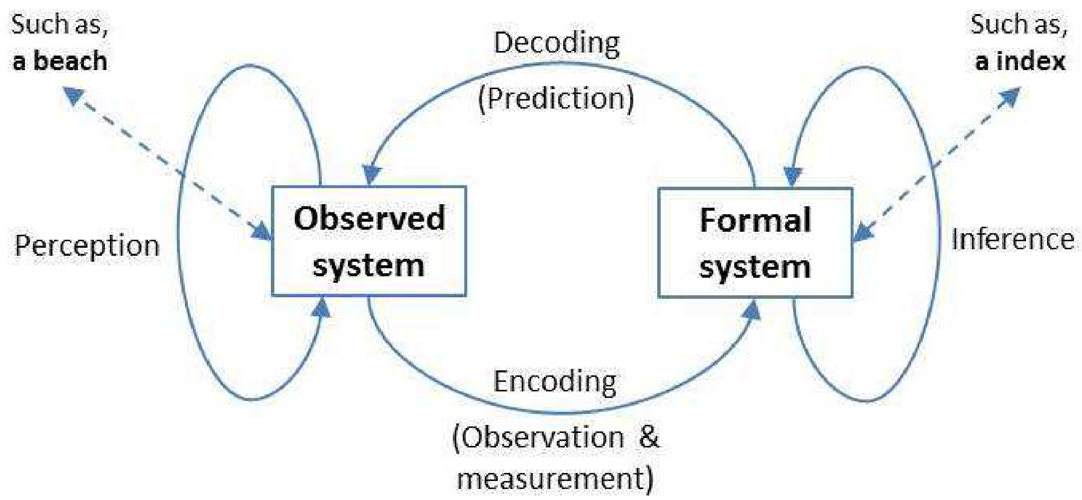

Figure 1. Rosen's modeling relation. Adapted from Giampietro et al. (2006) and Kovacic (2015).

A scientific model should, thus, include the following stages (Giampietro, et al., 2006):

1. A pre-analytical choice (perception arrow) regarding what, from the various possibilities and legitimate perceptions, may be relevant in the observed system to be represented in a formal structure;
2. An analytical choice (encoding, inference, and decoding arrows) regarding the means in which the representation of the selected perception should be formalized through a limited set of observable elements and processes.

So a scientific model is a simplification defined by the way we pose our subjective questionings, emphasizing that these are value laden. From the scheme of Figure 1, in the context of complexity, simplification may be discussed in terms of "an unavoidable relationship among the observer, the frame of reference and the extraction of partial and contingent truths" from the underlying observed complex system, which should be acknowledged (Allenby & Sarewitz, 2011, p. 114).

In order to put into light the values (i.e. representation of ideals) and interests behind the modelling of a complex system, an expanded peer review process should be undertaken, such that it would shed light on those peers behind the formalization of indexes, enabling indexes to be "quantitative expressions of narratives" instead of numbers overshadowing the centrality of words in explaining policy targets (Shields, et al., 2002; Garnåsjordet, et al., 2012). Narratives play a crucial role, particularly in the representation process (Kovacic, 2015). In this dissertation, the focus is made on the definition of relevant narratives as a base for the construction and measurement of indexes, following the steps of perception, encoding, inference, and decoding. Pertinence and usefulness were the main concepts of quality considered in the co-building of indexes that Kovacic (2015) classified as epistemological and pragmatic plurality for quality. Whilst pertinence, "an external criterion", may be achieved through adjusting the representation of a system (i.e. the beach) to the framing of problems, usefulness, "an internal criterion", refers to clarifying the outcomes of an analysis (e.g. a beach assessment) in relation to its purpose in a way that narratives pose context and give meaning to the represented items of a system in a model (Kovacic, 2015), e.g. the model of the double-looped BQI (Bombana & Ariza, 2019).

Opening up the process of modelling to other peers outside of academic institutions is not about denying the use of numbers traditionally claimed by science in a general spectrum, but about recognizing that they are not sufficient for the coding and encoding procedures implied in the building of models (Ravetz & Funtowicz, n.d.). Consequently, assessment of the quality of indexes should not prioritize precise numbers but their correspondence to social and political targets (Funtowicz & Ravetz, 1993). Giampietro and Saltelli (2014) asserted that only by the consideration of a multiplicity of narratives can quantitative assessment models and scales allow the adequate perception and representation of complex systems, incorporating the ontological and epistemological plurality of such systems.

Allen and Giampietro (2006) dedicated a paper—"Narratives and Transdisciplines for a Post-Industrial World"—to underlining such a potential role of narratives in addressing contemporary complex problems. They claim that a narrative is the expression of what is considered significant and important by the storyteller in a universe of dynamic and interrelated elements, processes, and scales, evidencing the non-objective reality of complexity through experience and relationships. There often is also a collective character of narratives, being the reflection of institutions' thinking (Bontje, et al., 2019). The meaning of the articulated point(s) of view, furthermore, is enabled by the context in which they are being explained and the actions they are guiding (Allen & Giampietro, 2006; Giampietro, et al., 2006). Narratives, thus, should be integrated into the procedures (arrows of Figure 1) in order to accommodate relevant objectives and targets (Garnåsjordet, et al., 2012).

My work departs from most of the previous work on sustainability indicators, which did not account for the plurality of narratives of relevant socio-ecological systems, and which paradoxically, promised certainty and objectivity through the modelling process (Ravetz & Funtowicz, n.d.). If I intended to correct some of the errors of these indicators using feedback from academics only, without questioning the underlying values used in the scientific process, it would constitute a single-loop (SL) learning process (Argyris, 1982). But, conversely and operatively, I integrated double-loop (DL) learning as the conducting wire of this thesis (more in Section 4, Research design), given that it refers to a process in which individuals and organizations question the usual rules and throw light on the arguments behind possible knowledge updates (Garnåsjordet, et al., 2012). This framework highlights the need for deliberative processes (i.e. expanded peer processes) enabling the analysis of primary assumptions and purposes of the set of indicators if we are to produce indicators for the assessment of sustainability (Garnåsjordet, et al., 2012).

2. CONTEXT

In this section, I place the research within the conceptual frame of coastal zone research and the analytical argument that traditionally the field has lacked a complex systems approach. With some exceptions (Vallega, 1999; Botero, 2013; Bremer, 2011), coastal management studies have often assumed a technocratic approach for the analysis and management of the coastal territory. In this line, I first review most common reductionist approaches to coastal zone research and discuss how this research could integrate complexity in order to overcome erosion management, a common problem of in the field. In Section 2.3, I narrow my focus to provide a brief review of the scientific reductionist approaches that have been widely adopted by beach management and, thus, introduce a call for more quality assessments as an objective to pursue in this research field. Juxtaposed with this reductionism, Section 2.4 maps beach systems communities.

2.1. The technocratic approach to coastal zone research

> "politics should not drive science; neither science nor engineering should produce numbers that cannot be defended" (Pilkey & Dixon, 1996, p. 74).

Since its creation in the 1970s, Integrated Coastal Zone Management (ICZM)[5] has been embraced for all geographical levels worldwide and expanded to different institutions as the reference framework to develop sustainable coasts (Sorensen, 1993). It is, however, still partially constrained by the illusion that more scientific knowledge will automatically lead to better management and that only in such a situation can action take place (Billé, 2008). A myriad of works based on such a belief (for example, GESAMP, 1999; Meltzer, 1998; UNEP, 2006; Nobre, 2011), besides obviating the urgency in decision making and believing the utopian task of entirely capturing the functioning of complex coastal systems (see Section 1.1), has indicated that the lack of formal scientific research in certain contexts (e.g. part of the Global South) would be limiting the applicability of ICZM.

In this sense, the main weaknesses of technocratic approaches to ICZM are: 1) the belief that all technical, financial, or human contributions can be transformed into policy outcomes; 2) the assumption that a linear and rational path will lead to an expected pre-agreed "end" between different parts; and, 3) the confidence that centralizing the decision process could make it easier, despite a wide call for the participation of stakeholders that often has taken the form of consultation (Bremer, et al., 2015).

More than 40 years of experience with ICZM practices have not prevented us from facing a series of "wicked" coastal problems that hold multiple changing facets in different time and space scales (Rittel & Webber, 1973). By being approached mainly from the perspective of scientific studies, the complexity of changing elements and relations could not be fully accommodated (Rittel & Webber, 1973), especially if their relation to values and interests is not brought to focus. Moreover, even within academia, contradictory perspectives about the same subject can be seen (Sarewitz,

[5] It is conceptualized as a process to manage specific resources or portions of coastal zones, through which desired objectives can be accomplished (Ehler, 2003).

2004). To cite some instances, a rising loss and modification of coastal habitats which threatens biodiversity and the associated degradation of ecosystem services have been defined as a global reality (UNEP, 2006), despite a growing number of studies in these subjects in the last 50 years, e.g. the exponential growth of sandy beach studies, partly focused on their resource use and management (Nel, et al., 2014).

Controversial and simplified solutions may arise from this panorama that, rather than demanding further scientific research, should focus on the political processes behind this research and their implications (Sarewitz, 2004). In the last 20 years, the emergence of coastal governance precepts has emphasized the call for an integration of other knowledge systems into the ICZM theory and practice, beyond the academic one (Bremer, 2013). That is, coastal governance should be a process where policies and decisions about coastal public issues are determined and enacted by a varied set of state, private-sector, and civil society institutions (Ehler, 2003), with limited aid from research organizations. Common to all governance instances is the idea of a complex issue identified and approached across a dynamic of interdependency between societal actors acting through new and traditional interactions (Kooiman, 1999; Bremer, et al., 2015).

2.2. Overcoming erosion management through the complexity approach

Already in the mid-1970s and 1980s, Bird and other scientists worldwide (Bird, 1983; Tanner, 1975) called attention to the global predominance of erosion on sandy coastlines (i.e. retreat of coastlines and reduction of the sand volume of beaches), potentially caused by multiple factors. This phenomenon, which has increased ever since (Eurosion Project, 2004), turned on the alarm of many localities and regions due to their economic dependence on sand and sea tourism and/or individual effects on coastal private properties (Phillips & Jones, 2006).

The main responses applied to solve the problem are: 1) building hard shoreline stabilization (e.g. seawalls, jetties, etc.), 2) developing soft shoreline stabilization (i.e. beach nourishment), and 3) retreating from the coast (i.e. moving buildings inland, dismantling them, or accepting their fall into the sea) (Pilkey-Jarvis & Pilkey, 2008). To date, the first two have been the most commonly used; however, they have shown an inability to properly solve the problem in question. As Pilkey-Jarvis and Pilkey (2008) stated regarding hard coastal works, “They almost always create more problems than they solve. If they cause sand to accumulate at one point on the beach, which is usually the desired end result, they rob sand from another point…. But beaches must be free to survive and thrive” (p. 119). As far as relating to beach nourishment works, sediments usually persist much less *in situ* than primarily defended by those responsible by designing and applying the aforementioned coastal works (Pilkey & Dixon, 1996), obviating here their negative impacts on coastal fauna and flora (Peterson & Bishop, 2005).

Predictive work developed for the first two strategies above, which is based on mathematical models, has been demonstrated to be of low precision (Pilkey-Jarvis & Pilkey, 2008). Beaches are quite dynamic complex systems where simultaneous interacting physical processes (e.g. waves, currents, and sediment transportation), operate in a trans-scalar way, and are often poorly understood. In this line, Pilkey and Dixon (1996) argued that not a single successful application of models predicting the behaviour of beaches and potential erosion has been documented. Indeed, they have been proven to be very limited in their aid for sediment management practices given that they incorporate non-reported poor assumptions, relationships of questionable validity, and mis- or non-application of calibration and verification/validation procedures (Thieler, et al., 2000).

The management of the models' shortcomings, nonetheless, does not address the associated ethical issues, such as the allocation of public taxes or the negative impact on non-material values. Some alternatives to these models, thus, have been proposed to better cope with the complexity of beaches; these are based on monitoring and learning of past actions, e.g. if we are to design a nourishment project for a certain beach, we should base it on past experiences at neighbouring beaches (Cooper & Pilkey, 2004; Pilkey, et al., 1994). Recalling the strategies mentioned above, if our aim is to save coastal infrastructure and buildings in the short term, then strategies 1 (building hard shoreline stabilization) and 2 (developing soft shoreline stabilization) must be applied, every now and then, to stabilize the shoreline; but if the aim is to protect beach socio-ecological systems for forthcoming generations (considering users and natural heritage) we should focus on strategy 3, retreating from the coast (Pilkey-Jarvis & Pilkey, 2008).

In the decision-making sphere about which of the mentioned strategies should be chosen, economic reasoning habitually predominates when proposing actions for tackling erosion, particularly evidenced by cost–benefit analysis that takes into account calculations made by mathematical models (Cooper & McKenna, 2008). Contradictions concerning this analysis abound: inaccuracy, exclusion and neglect of social and environmental considerations, and aggregation of benefits. In addition, there is the classic assumption that well-being could be well represented by income and that all assets can be quantified in monetary terms (Boda, 2018a). In fact, "if it weren't for the cost–benefit ratio problem, beach modelling would probably reside only in academia and not be a part of our society's political maelstrom" (Pilkey-Jarvis & Pilkey, 2008, p. 121).

In order to make decisions about which strategy to take, Boda (2018a) suggested social choice—a deliberate and public process for contrasting information and knowledge—as an alternative to economic choice (e.g. cost–benefit analysis) and political choice in the sense of reaching consensus from a majority of votes or voices. Social choice integrates a perspective of development through and for freedom in which the decision should be intended to remove the unfreedoms (e.g. political limitations and lack of economic facilities, social opportunities, and transparency guarantees) that people may have been suffering (Sen (2001) in Boda, 2018a). For example, in the case of Spain, rudimentary communication about using public taxes to nourish certain points (beaches) of the coast can be interpreted as something to be tackled within this perspective. In other words, by using beach complexity as a means to expand the approach to erosion problems, we could focus on more sustainable, transparent, and socially just proposals (Cooper & McKenna, 2008) where the shortcomings of mathematical models and cost–benefit analysis could be counteracted, besides the ethical decisions affecting how, why, and who will benefit from the potential decision taken.

2.3. Scientific reductionism in the management of beaches and the call for quality assessments

In spite of the fact that ecological descriptions of beaches started in the mid 1940s (McLachlan, 1980), the conceptualization of (sandy) beaches as ecosystems is a "relatively new and emerging discipline" (Nel, et al., 2014). The first important reference to beach systems, integrating ecological, physical, social, cultural, and managerial processes, was developed by James (2000). His study explicitly criticized the often exclusive framing of beach management research in terms of geomorphological hazards and recreational use. It may be said that this "'hazards-and-playgrounds' view" (James, 2000, p. 496) has been adopted by a majority of coastal scientists, primarily from a technocratic perspective (examples were given in the last section), occasionally considering beach users' input to define priorities and management satisfaction (Peña-Alonso, et al., 2018; Williams & Micallef, 2009).

At least in the case of the Global North, quality/environmental tools designed for the management of beaches have been claimed to have a certain capacity to encourage recreational quality uses, at the same time that environmental degradation is being tackled (Roca & Villares, 2008; Sardá, et al., 2015). The influence of these quality tools on policy started in 1987 with the European Blue Flag award and has evolved to more systemic alternatives (e.g. certification standards from environmental management systems) that put the focus on environmental management procedures, such as the waste management cycle. Nonetheless, in recent years, criticisms have been made about the wide application of such tools, given that some adaptations to properly integrate elements of internationally agreed environmental policies are still missing, e.g. recognition of beaches as natural systems for which protection and recovery efforts should be set up (Sardá, et al., 2015; Fraguell, et al., 2016). The Blue Flag, in particular, despite its advancement as an "ecolabel" (Fraguell, et al., 2016) and its "aiming at promoting seaside tourist destinations" (Capacci, et al., 2015), should be primarily considered a tool for tourism promotion rather than for environmental management. Many of the beaches bearing this credential have poor environmental status and high overcrowding (Ariza, et al., 2008a; Klein & Dodds, 2018; Mir-Gual, et al., 2015; Roig-Munar, et al., 2018). However, the positive relation between Blue Flag implementation and touristic benefits is yet to be demonstrated (McKenna, et al., 2011; Nelson & Botterill, 2002). Adding insult to injury, certification schemes have been established through top-down approaches, obviating democratic practices and context-specific epistemologies.

In this context, the consideration of users' perceptions for the design of these tools has been defended as a means to deliver more comprehensive management due to the potential inclusion of users' expectations in terms of recreation and conservation of the natural heritage (Roca & Villares, 2008; Roca, et al., 2009; Vaz, et al., 2009). Nonetheless, the best management practices are not always in agreement with what is perceived by users (McFadden, 2008), and differences may be found among them, who are usually tourists less concerned than are residents with the natural beach values and environmental degradation (Roca, et al., 2009; Presenza, et al., 2013).

Some authors have also called for an ecosystem-based management system for beaches (EBMS-Beaches) to tackle the reductionism of studies and tools for beach management, by adding those aspects not perceived in classical approaches through principles such as a holistic approach, ecosystem services schemes, and participation of local civil society (Sardá, et al., 2015). EBMS-Beaches is constituted by the managerial, information, and participatory pillars, underlining adaptive management concepts, updated scientific information, and the higher involvement of stakeholders within a governance structure (Sardá, et al., 2015). This framework asserts its potential to include stakeholders beyond academics and users, but questions arise regarding the quality of the updated scientific information, the type of participation, and how this can integrate the different narratives in play since the beginning of beach management procedures.

Assurance of the quality of coastal (and beach) management in the terms perceived by the present study (Section 1.2)—both an objective and a process in which expanded peers are central—has started to be proposed by some scholars in recent years (Bremer & Glavovic, 2013b; Bremer & Glavovic, 2013a; Grilli, et al., 2019; Udovyk & Gilek, 2014). Behind this discourse is the necessity to recognize and accommodate all knowledge systems capable of explaining beaches, potentially enhancing, amongst others, transparency and honesty in this endeavour (Bremer & Glavovic, 2013b).

2.4. Beach systems communities

Suárez de Vivero and Rodríguez Mateos (2005) pointed out that ICZM and, consequently, beach management are primarily a political process. That statement seems natural when beaches are considered as a public and common good (Ostrom, 1990), subject to non-equivalent descriptions and valuation languages (Giampietro, et al., 2006; Martínez-Alier, 2009) by a plethora of stakeholders affected, interested, and/or responsible for such systems (Pomeroy & Douvere, 2008). However, the number, variety, and intensity of relationships of stakeholders within beach systems have been often neglected by beach management studies.

Exceptionally, some studies have, in fact, pointed out the diversity of stakeholders related to beach management in different contexts (Barragán Muñoz, 2010; Ariza, et al., 2014; Williams & Micallef, 2009; Bombana, et al., 2016; Trejo Sánchez, 2018). This multiplicity, though it can be a source of opportunities and ideas, can also be a source of conflict. Boda (2015) reminded us that, in potential instances of coastal management, power-rationality relations between parts naturally emerge which, influenced by historical roots (e.g. past research and actions endured) and being context dependent, limit the level and type of participation. These interactions should be acknowledged by the beach management initiatives, given that the consideration of stakeholders and the quality of their discourse/integration will constrain the way processes and outcomes are to be explained and creatively developed (Boda, 2015).

One way to reveal how stakeholders interpret the position and actions of others and how they understand processes and may propose actions is through the use of storytelling, usually confirming the existence of contrasting beliefs about conflicts of the coastal zone as well as how these conflicts should be addressed, and by whom (Allen & Giampietro, 2006; Bontje, et al., 2019). Despite this capacity of narratives to provide meaning and understanding into debates for beach management, they have been understudied (Bontje, et al., 2019). In fact, in Catalonia, where a myriad of institutions is also observed (Breton, et al., 1996; Romagosa & Pons, 2015; Ariza, et al., 2016), the analysis of relevant narratives has not been performed to date. This has limited the understanding of how beaches are socially constructed. In the next chapters, I will provide further details on this subject.

3. CASE STUDY

The case study of the Catalan beaches is presented in this thesis. I begin by introducing the Spanish and Catalan coastal zone regulatory framework to define requirements for coastal development and natural protection and contextualize scientific demands and coastal policy developed since the early 1990s. Then I summarize the multidimensionality of Catalan beaches by underlying their most prominent characteristics, processes, and features to highlight their condition as socio-ecological systems. Lastly, I illustrate some of the main conflicts of Catalan beach systems, both old and new, that justify the call for a science for governance, assuming that this could help to provide some answers for these conflicts.

3.1. The Spanish and Catalan coastal zone regulatory framework

> "As in most of the countries on the western Mediterranean, there is no integrated coastal management with a strong legal and institutional basis in place in Spain" (Suárez de Vivero & Rodríguez Mateos, 2005, p. 209).

Despite repeated initiatives to launch a formal framework for ICZM in the country, such as Recommendation 2002/413/EC of the European Parliament and Council, or the ICZM Protocol for the Mediterranean, there is no particular law regulating the integrated management of the littoral space in Spain. Instead, the Spanish Coastal Law ("*Ley de Costas*"—LC, 1988) and a subsequent Royal Decree (1989) and amendment (Law 2/2013) regulate the Spanish maritime–terrestrial public domain (MTPD) and surrounding areas, defining land use planning requirements in the first 500 meters of the coastal zone. The requirements which are in place at the top of the regulating hierarchy are incorporated by all other planning instruments operating in this space (such as the Natural Heritage and Biodiversity Act 42/2007, the Bathing Water Directive 2006, and the Marine Strategy Framework Directive 2008/56) (Barragán Muñoz, 2010; Montoya Font, 1995). Amongst other things, the law sets up protective measures for coastal public domain assets, including beaches, ensuring their public use in accordance with their nature. At the same time, the law defines the responsibilities of the local, regional, and national administration agencies (Montoya Font, 1995).

Responsibility over the management of certain coastal assets (water resources, protected areas, etc.), particularly coastal planning and territory regulation, has been transferred to regional administrations in several Spanish regions in accordance with their Statutes of Autonomy (Barragán Muñoz, et al., 2011), regardless of the lack of an adequate transfer of funding (Ariza, et al., 2016). Though the Statute of Autonomy of Catalonia (2006) confirms, in article 149, that Catalonia retains governance over this area, coastal planning is still subject to general rules of the State about the MTPD formalized by the LC (Aguirre i Font, 2015; Ariza, et al., 2016). From here, the Catalan Government (*Generalitat de Catalunya* - Gencat) turned specifically responsible for designing and implementing beach management plans and for allowing the occupancy and use of this domain (Ariza, et al., 2016). Other regional practical instruments regarding the management of the coastal territory arose, such as the *Plan Director Urbanístic del Sistema Costaner* (PDUSC) (that prevents the urbanization of the 20m–100m hinterland of beaches), the creation of natural protected areas (Suárez de Vivero & Rodríguez Mateos, 2005; Aguirre i Font, 2015), and the transference of responsibilities from the Spanish State to the Government of Catalonia in what are referred to as grantings (Royal Decree 1404/2007, of 20 October and 1387/2008, of August 1).

An amendment of the Spanish LC in 2013 (LC 2/2013), however, has been interpreted as a step back in the management and conservation of the coast, because the amendment treats it as "an economical space … where what matters is the economical profitability and the legal security of the administrative acts and transactions" (Losada, 2013, p. 51), whereas it marginalizes its dynamism, ecological importance, and evolutionary rhythm (Losada, 2013; Pons Cànoves, 2015; Ariza, et al., 2016). It operationalizes the economic profitability through, amongst other things, reducing the protective fringe surrounding the MTPD, poorly defining and subsequently declaring the major part of the coast as "urban", and expanding the time period of concessions in the MTPD, which would allow for more urban developments to be carried out (Losada, 2013).

Based on this context and the progressive degradation of coastal assets, part of civil society, scholars, political representatives, and ecological institutions have advocated the development and approval of a coastal law for Catalonia that, though limited to regional competences, could aim at protecting the coastal landscape and resources through restricting the criteria of LC 2/2013 to prevent further urbanization, e.g. ensuring protection for natural beaches and prohibiting concessions to build new nautical facilities on the beaches (Pons Cànoves, 2015). Even if this occurs in the near future, it would still be early to say that it would contribute to a proper ICZM in a sense that state, autonomous, and municipal governments (obviating here the expanded set of peers) could be both longitudinally and transversally interacting in plans, actions, and tools aimed at achieving sustainability for the Catalan coast (Suárez de Vivero & Rodríguez Mateos, 2005).

3.2. Catalan beaches as multidimensional systems

The Catalan coast (Figure 2), located in the north-western Mediterranean, is internationally known primarily for some of its tourist destination brands, e.g. *Costa Brava* and *Costa Daurada*. These brands contribute (though not exclusively) to attracting one-quarter of the tourists arriving in Spain (one of the top three most visited countries in the world), resulting in 19.7 million visitors in Catalonia in 2018 (INE , 2018). However, the Catalan coast is visited and valued not only by international tourists but also by Spanish tourists and Catalan residents (Roca & Villares, 2008). This is due to the rich diversity of landscapes, geomorphological environments, and natural habitats integrated within its 700km of coastline (Serra & Foz, 2015).

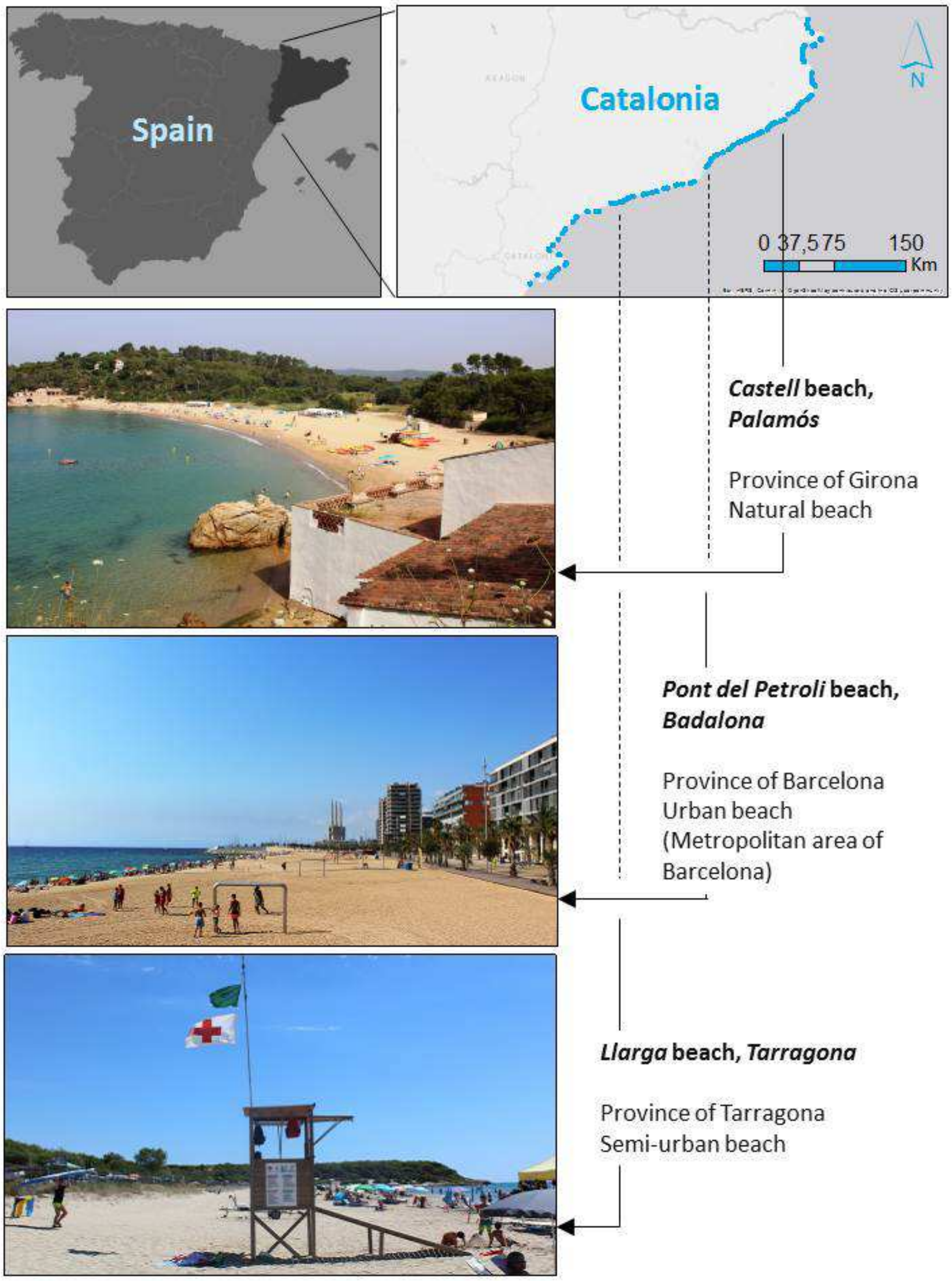

Figure 2.The Catalan coast (north-western Mediterranean, Spain) and three examples of its beaches: *Castell* (natural beach in the province of Girona), *Pont del Petroli* (urban beach in the province of Barcelona) and *Llarga* (semi-urban beach in the province of Tarragona). Source: Own elaboration.

Effectively, it was the advent of a culture that valued the coastal landscape in the first decades of the last century that turned the attention to this landscape and other assets, still perpetrated today. With this attention came urbanization and fragmentation of the territory and consequences in diverse fields, such as the substitution of first-sector economic activities—e.g. fishing—by tertiary-sector activities related to tourism and leisure (Martí, 2005). The patrimonial value of this coast has contributed to a high density of population in this area, counting 10.500 habitants/km (Serra & Foz, 2015), even higher in the case of the metropolitan region of Barcelona, which is the most urbanized coastal segment in Spain. It is noteworthy that such density is subject to increases in high season (primarily during the summer) due to the sand and sea tourism; consequently, this also increases beach attendance. Mostly because of the corresponding flow of people, economic revenues cannot be detached from the analysis of beaches. Some economic valuation methods have demonstrated that in some parts of the Catalan coast, direct and indirect activities at beaches may produce more than 1 million €/day, in contrast to the management investments made (usually less than 1 million €/year) (Ariza, et al., 2012).

This together with the recent sprawl of urbanization, that was somewhat curbed by protests and other movements from organized civil society mainly arguing for the conservation of coastal heritage (Massó & Solé, 2019), has demonstrated that even after more than a century of exploitation, the Catalan landscape continues to be valued and desired and has maintained some important valued assets and processes. For example, solely within the littoral fringe (*supra, medio, and upper infralittoral*) there still can be found 53 different habitats comprising the marine environment: tide rivers, estuaries, and delta embankments; sandy beaches and dunes; pebble beaches; cliffs and rocky coastlines; and ports and artificial lagoons and channels (Departament de Territori i Sostenibilitat, 2014a). From the geomorphological point of view, Catalan beaches can present characteristics of abrupt (e.g. rocky pocket beaches of *Costa Brava*), low (e.g. open or semi-exposed beaches of *Costa Daurada*), or deltaic (e.g. open exposed beaches of the *Ebro Delta*) coasts (CIIRC, 2010).

In spite of the multidimensionality of beach systems recognized by researchers and international institutions, the case of Catalan beaches shows that they are almost exclusively managed, at the national, regional, and local scale, as buffer zones protecting the coastal urban structures from destruction or erosion by the sea and/or as places for the development of recreational activities related to both tourism and leisure. This is because private interests and sectorial practices are the main conditioners of more integral ways to approach them (Ariza, et al., 2016). From this there is a great distance to a "socio-ecological culture" where integrative instances would enable different values, scales, and narratives to be taken into account (Ariza, et al., 2016).

In this thesis, I do not approach beaches by the traditional conception of their most widely recognized functions—protection and natural and recreational activities (Ariza, et al., 2010)—because these usually limit the analysis to few or simplified processes (MEA Board, 2005), ignoring other important ones, e.g. maintenance of wildlife and soil retention (Barbier, et al., 2011). Hence, I prefer to use dimensions as an organizing concept, which allow one to aggregate one or more beach functions, assets, and processes within a level of analysis that is broad enough to include specific management objectives and corresponding tools (Munda, 2005). Catalan beaches, thus, are here approached through the following dimensions (Bombana & Ariza, 2019, p. 181):

1. Recreational activity: The set of recreational activities developed within the (visible and submerged) beach area and surroundings, as well as beach users' responses and preferences;
2. Morphodynamics: The interactions among coastal floor, sediments, and hydrodynamic agents (e.g. waves and coastal rivers), as well as the anthropic activities affecting such interactions (e.g. beach nourishment);
3. Ecology and natural heritage: The biotic communities, non-biotic assets, and interactions capable of forming and running the corresponding ecological system and natural heritage;
4. Beach economics: The monetary transfers resulting from the use of beach resources and activities, and further outcomes;
5. Governance and management: The decisions, tools, and dynamics that put in practice coastal management plans and programs. These should occur besides the government sphere, through the inclusion of other institutions and collectives.

3.3. Old and new conflicts in Catalan beach systems

"Barcelona will reduce the beach bars and loungers to fight against saturation" (CCMA.cat, 2018). This statement describes much of the main conflict about beaches currently in place in Catalonia—the overexploitation of a (sometimes not so) natural system for the development of recreational activities —which has been described and already detected in other works (Roca & Villares, 2008; Lozoya, et al., 2014; Dadon, 2018). This conflict, however, is accompanied by a list of problems, which are interrelated among themselves (Table 1).

Table 1. Brief description of the major problems of the Catalan Coast.

Conflict	Description	Source
Overcrowding	Mainly urban and semi-urban beaches of Catalonia receive a high number of users during the high season, who tend to concentrate at the beach during a few hours daily.	(Roca, et al., 2009; Sardá, et al., 2009)
Erosion	Catalan beaches are losing sand over the long term; much of this is due to construction work performed in the surrounding areas.	(CIIRC, 2010; Ariza, et al., 2008a)
Depletion of dune systems	The majority of dune systems in Catalonia are negatively impacted by human action, unfolding a state of underdevelopment.	(Garcia-Lozano & Pintó, 2018)
User demands	Beach users demand different management actions on beaches, such as the supply of services, facilities, and cleaning. Nevertheless, different patterns of preferences are observed depending on the type of user (tourists or local users).	(Roca, et al., 2009)
Waste and litter pollution	The production, transportation, and accumulation of waste and litter in the sand strip, water, and surrounding areas.	(Ariza, et al., 2008b)

The roots of the present problems can be traced to the economic importance of tourism and coastal real estate in the region. In Catalonia, tourism contributed to 10%– 15% of the GDP in the first decade of this century (Duro, et al., 2010), a pattern which continues till today. In that regard, beach policy since the 1960s has been focused on providing recreational services and facilities. This trend was deepened by the interest of coastal municipalities in obtaining the Blue Flag international quality award as well as other credentials, also focused on user satisfaction, since the late 1980s. Conflicts and problems (Table 1) began to be intensified, such as the requirements for mechanical cleaning that contributed to the depletion of dunes (Garcia-Lozano & Pintó, 2018). The national and international tourism demands triggered the coastal development boom of the 1970s, which severely transformed the coastal territory (Martí, 2005). Building on littoral forest and dune systems and construction of sea promenades were generalized. In order to protect coastal infrastructure, hard engineering works were subsequently built along the littoral area of Catalonia (Sanò, et al., 2011). The consequence of this process, along with the decrease in the provision of sediments through river basins, was the disappearance of much of the autochthonous flora and fauna, the degradation of the landscape, the banalization of the human–nature relationship on beaches, and the intensification of erosion trends. Since the 1980s, and following a general trend in the Mediterranean, most Catalan beaches have eroded (Sanò, et al., 2011). In Catalonia, in 2010, more than 70% of beaches were eroding (CIIRC, 2010). The reduction of beach space, that is being enhanced by the sea level rise (SLR) resulting from climate change (Zorrakino, 2019), combined with an intense use of beach recreational areas, underline a massification of many beach systems during high season, especially in the summertime.

Today, different authors and institutions have been pointing out the degradation of Catalan beach systems (Ariza, et al., 2016; Garcia-Lozano & Pintó, 2018; Greenpeace España, 2013; Ecologistas en Acción, 2019). Main degradation hotspots (those displaying critical pollution and poor environmental management) have been identified and designated as “Black Flags” by Ecologists in Action (from the Spanish *Ecologistas en Acción*, which is a grassroots confederation of ecological groups of Spain), as in an ironic allusion to the Blue Flag certification scheme. The main causes emphasized are wastewater discharge, industrial chemical spills, urbanization and subsequent depletion of natural assets, and coastline regression (Ecologistas en Acción, 2019). On the other hand, *Ecologistas en acción* also delivers an award to “pristine beaches” (*platges verges,* in Catalan), with the intention of alternatively valuing the parts of the territory that are still well preserved and protected from the impacts of mass tourism and anthropic pressures (Ecologistas en Acción, 2016).

Taking into account that regardless of beach management efforts and studies applied to this territory in recent decades, these insights show a continuous perpetration of general degradation practices of beaches and surroundings, so that I highlight the need for new, creative, and transparent instances in order to capture the high diversity of Catalan beach conflicts. The current criticism on the boundaries of the science for policy (Funtowicz & Ravetz, 1993; Sarewitz, 2004; Bremer, 2013) call for a multiple set of knowledge systems beyond the academic circle and the government responsible for delivering practical actions in this regard. Indeed, this is also advocated by organized civil society in itself in some cases (Massó & Solé, 2019), having the potential to create or disrupt current institutions (Bontje, et al., 2019). In particular, more open scientific practices might identify knowledge gaps that were not observed before and, hence, integrate non-scientific monitoring into strategic knowledge interchange for long-term management processes (Bremer & Glavovic, 2013b).

4. RESEARCH DESIGN

I will start this section by making explicit the motivations behind this dissertation. In the theoretical sphere, there is a need for advancing on current conceptualizations of complexity if we are to produce science capable of aiding policy actions regarding beach management. So far, the limitations on designing and applying useful beach management tools have been understudied and usually ruled by a "positivist" view of how coastal management could be enhanced by more scientific knowledge (Billé, 2008). Those characteristics of complex problems observed in beach systems—non-reducibility, spatial and temporal variability, uncertainty, collectivity, and spontaneity (Dryzek, 1987)—should be acknowledged and incorporated into scientific practices in a context of urgency in decision making, high stakes, and deep uncertainty, as recalled by the PNS framework (Funtowicz & Ravetz, 1993). PNS has been advocating for an expanded peer review that is potentially more capable of addressing the challenges of complex systems mainly because it sets the base for a plurality of epistemologies which explain complex problems. Hence, in the practical sphere, I address these advancements by proposing, checking, and assessing the application of a beach management tool built within the characteristics of the PNS framework. I provide these insights through the use of what I believe is an expanded assessment of the knowledge quality, enabled by a DL learning process: from step 1—selection and definition of indexes—through step 2—production, step 3—assessment of indexes, and step 4—information for policy (Garnåsjordet, et al., 2012). As briefly mentioned before, evolving from a SL process that includes academic feedback on technical issues, the DL process ingrates feedback by other peers which also implies "changes in the rules themselves and make[s] explicit the arguments for these changes" (Garnåsjordet, et al., 2012).

4.1. Research questions and objectives

a) Research questions

The research can be understood as a flexible and adaptable process. The objectives and links between results can be structured around **three main questions**:

Question 1. What are the most relevant values and uncertainties embedded in beach quality indices developed so far? How strong are they?

Question 2. How does a DL learning process contribute to the co-production of a more useful and pertinent tool in the context of complexity in this science–policy study case?

Question 3. What is the current status of Catalan beaches looking at quality assessment?

b) Objectives

This approach and these questions are thus condensed in the **general objective** of this thesis—**to co-produce indexes for the beach management of Catalan beaches**—unfolded in three specific objectives:

Specific objective 1. Assess the scientific assumptions behind the beach management tools proposed so far, particularly the one developed for the Catalan coast.

Specific objective 2. Develop a new beach management tool for the Catalan coast by enhancing its pertinence and usefulness.

Specific objective 3. Assess the sustainability of Catalan beach systems and the capacity of the new tool for providing quality knowledge for policy.

Answers to the questions were developed and deepened in the publications that comprise the present work and are presented in the following chapters.

4.2. Justification of the thematic unity

The make-up of this thesis is based on the three publications[6] presented sequentially. They are strictly related through the framework of the DL process for producing indexes for policy actions (Garnåsjordet, et al., 2012), given that they follow the four phases and include feedback of this pathway: from the analytical framework to the empirical research, including brief information for policy. In the first article, I approached the first part of step 1—selecting and defining indexes; in the second, I followed the selection and definition of indexes, leading to step 2—production of indexes—as the second phase. Finally, in the third and last contribution, I develop steps 3—analysis of indexes—and 4—the subsequent information acquired for policy. Such a linear continuity makes particularly evident the argumentative thread of this thesis, whilst the relationship of the defined specific objectives of each of the publications is evidenced in Table 2.

Table 2. Relationship between specific objectives and the publications comprising the present thesis.

Publication	Specific objective	Publication title	Citation
1	Assess the scientific assumptions behind the beach management tool proposed so far, particularly the one of the Catalan coast	Clarifying some assumptions of coastal management: Analysis of values and uncertainties embedded in beach quality indexes	(Bombana & Ariza, 2018)
2	Enhance the pertinence and usefulness of a Catalan beach management tool	A double-loop process for beach quality index construction: Approaching the complexity of the Catalan coast	(Bombana & Ariza, 2019)

[6] The third and last one, though still not published, has been designed to be submitted to a scientific journal as soon as possible.

[Continuation of Table 2]. Relationship between specific objectives and the publications comprising the present thesis.

Publication	Specific objective	Publication title	Citation
3	Assess the sustainability of Catalan beach systems and the capacity of the new tool for providing quality information for policy	Multi-dimensional assessment of Catalan beaches (Spain) from a pragmatic and epistemological perspective	In process

Each specific objective has been defined to answer one of the research questions in each of the three publications. The first article addressed the approach of values and uncertainties, underlined by the first research question, by identifying and assessing the main scientific assumptions behind the structure of a tool for the management of Catalan beaches—the Beach Quality Index (BQI) (Ariza, et al., 2010)—which was built by an interdisciplinary group of academics in Catalonia. The expanded peer assessment (EPA) of the DL process of learning based the assessment of assumptions behind the BQI (now named the single-looped BQI, SL-BQI) and of its structure (i.e. composing sub-indexes and variables), resulting in its update into the double-looped BQI (DL-BQI). The DL-BQI development is presented in the second article. I thus tried to align the framing of problems found in the Catalan coast and the DL-BQI, and to improve the coherence between the potential outcomes of this tool with the co-defined objectives for the Catalan coast, corresponding to the enhancement of pertinence and usefulness (Kovacic, 2015). This work has been carried out to answer the second research question. Finally, the third article presents an assessment of the current state of Catalan beaches in a context of an expanded review of the knowledge produced, double-checking the outcomes provided by the application of the DL-BQI. I believe and demonstrate that the presented knowledge implied a higher quality in the sense of PNS standards, so that some suggestions for beach management in Catalonia were made in this science–policy interface, providing a response to the last research question.

As will be evident, the three publications share the same theoretical and general methodological framework. The second and third publications could not have been developed before finishing the previous one, and at the same time, they are the next logical steps in a complete co-production of knowledge process. In the following section, further details about material and methods are supplied.

5. PRACTICAL APPROACH

The present section details the general methodological set carried out to address the objectives of this thesis, as illustrated in Figure 3. In the chapter corresponding to the publications, more extended and detailed descriptions of the particular procedures and techniques used to answer the corresponding specific research questions are provided.

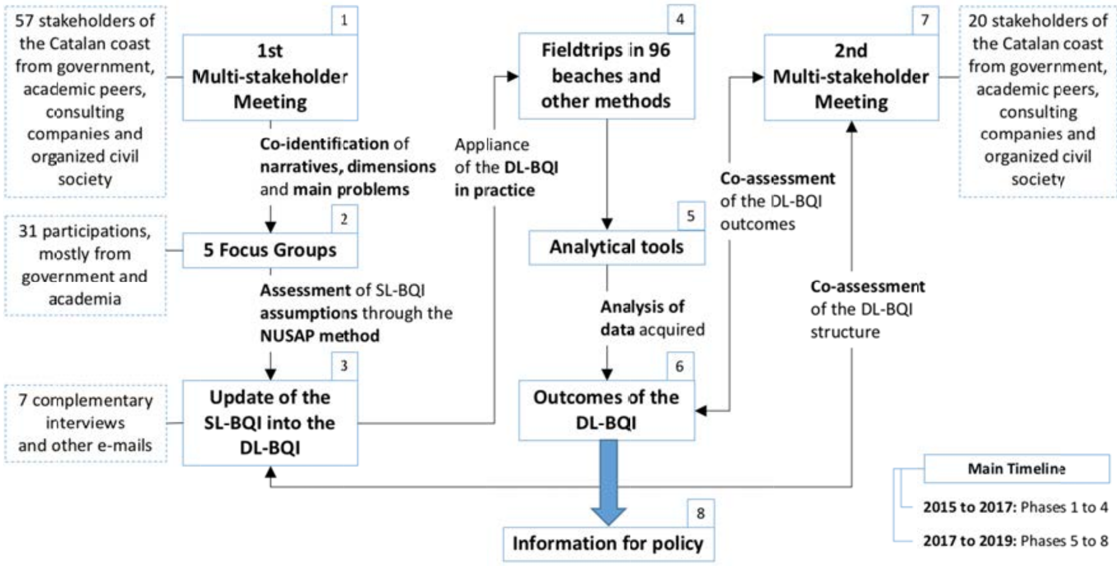

Figure 3. Methodological set used in the present thesis to reach the general objective proposed. While the information compiled in phase 1 of this set was transversal to all steps of the DL process of learning (Garnåsjordet, et al., 2012), starting with step 1 - selection and definition of indexes, I may say that phases 2 and 3 were mainly related to the former step and to step 2 - producing indexes, and phases 4 to 8 to the steps 3 and 4, i.e. the assessment of indexes and information for policy. Source: Own elaboration.

Given that the main objective of this thesis was to co-produce indexes for the management of beaches on the Catalan coast, I should underline what I understand by co-production. It is a process in which the production of scientific information is discussed through a wider set of knowledge claims (beyond academics) in a language that does not give superiority to either, so that the social and technical scientific determinism is avoided (Jasanoff, 2004). To do that, I followed the eight major phases highlighted in Figure 3. Phases 1 to 3 contributed particularly to the achievement of objectives 1 and 2 (respectively, to assess the scientific assumptions embedded in the beach management tools created before my research began, particularly the one for the Catalan coast, and to enhance the pertinence and usefulness of a Catalan beach management tool), whilst phases 4 to 8 helped to reach objective 3 (i.e. to analyse the sustainability of beach systems in Catalonia and assess the capacity of this tool for providing information for policy).

It also should be mentioned that this co-production of indexes does not depart from ground zero because it uses the first set of indexes to measure the status of Catalan beaches—The Beach Quality Index (BQI) (Ariza, et al., 2010; Ariza, et al., 2012) (Figure 4)—as a base. Its main innovation was to create an interdisciplinary academic team that initiated a discussion to conceptualize and assess beaches from a systemic perspective. In that sense, the tool was structured by means of three interrelated blocks (recreational, protection, and natural functions) in a SL learning process (Garnåsjordet, et al., 2012): feedback was restricted to that of scientific experts after its application to six Catalan beaches, and no assessment of its assumptions was included during this process. I name this new index the Single-Looped Beach Quality Index (SL-BQI).

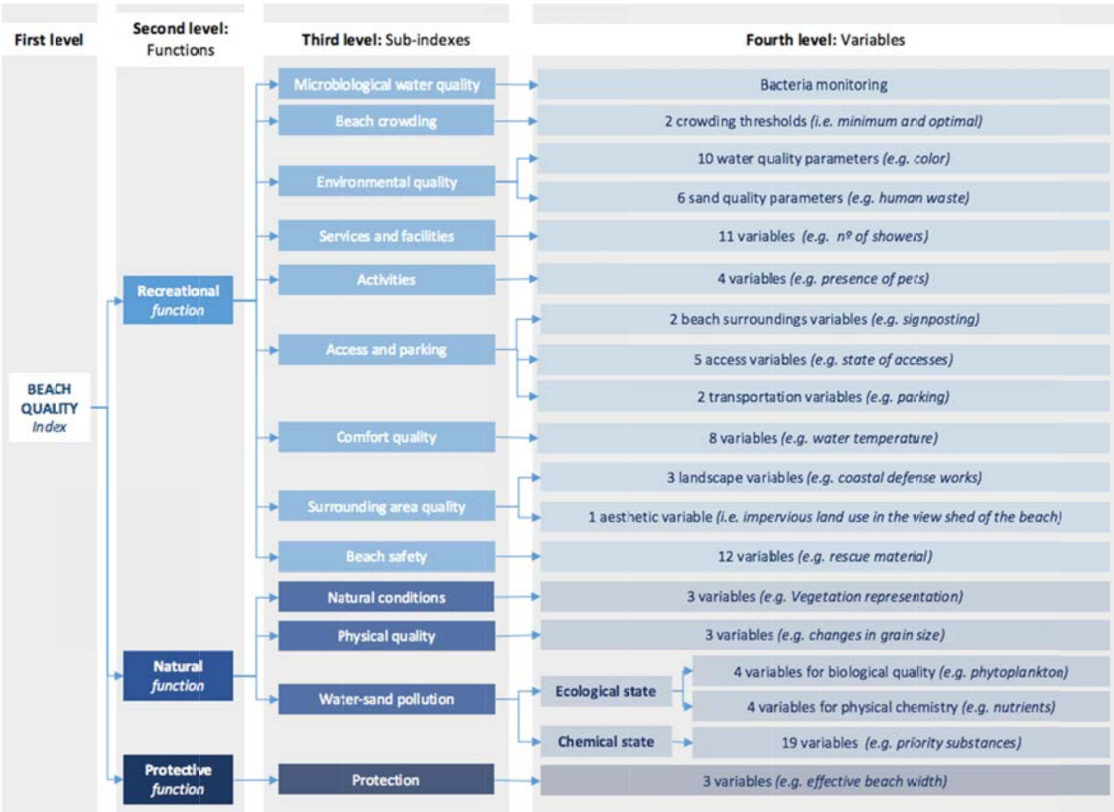

Figure 4. The structural organization of the (SL-)BQI components. Adapted from the (SL-BQI) (Ariza, et al., 2010).

In Section 5.1, I review the expanded peer review procedures, referring to the two multi-stakeholder meetings (MS-meetings) and the five focus groups (FGs) carried out, comprising the core of the co-production practice. Section 5.2 briefly explains the structure of the DL-BQI, the set of indexes for beach management designed and applied in the Catalan territory. Field works and applied methods/techniques of data collection are presented in Section 5.3. In Section 5.4, the analytical tools and statistical tests used for processing and analysing data are presented; and, finally, the limitations of the approach are explained in Section 5.5.

5.1. The expanded peer review

The theoretical framework discussed above strongly recommends an expanded peer review of the produced information—which also can be titled citizens' juries, focus groups, or consensus conferences—given that it is considered an alternative to create quality information for policy under conditions of complexity (Ravetz & Funtowicz, n.d.). According to Kønig, et al. (2017) based on Funtowicz and Ravetz (1993), a PNS methodology aiming at the enhancement of knowledge quality combines an external and internal expanded peer community that makes allusion to, respectively, the integration of relevant stakeholders beyond the academic circle and to the interdisciplinary reviews by experts, including also more informal sources of facts and documents, such as investigative journalists.

In this thesis, I carried out the expanded peer review through the development of two MS-Meetings and five FGs. A total of 108 direct participations[7], beyond the community of scientific experts, were registered. The FGs differentiated from the MS-meetings as they had an exclusive focus on each of the five identified beach dimensions—recreational activity, ecology and natural heritage, morphodynamics, beach economics, and management and governance—with each group including a maximum of seven participants (Bryman, 2012). Complementarily, to address the eventual lack of particular information, I proceeded to contact experts individually, totalling seven extra interviews, four respondents of an online survey, and a few e-mail exchanges.

The MS-meetings and FGs

The first MS-meeting (Figure 5) was integral to the whole process, as it allowed the co-building of the key concepts from which the different steps of the research were developed: 1) list of the main conditions, trends, positive processes, key stakeholders, and problems of the Catalan coast; 2) main narratives explaining the items on this list; and 3) main dimensions in which beach processes are occurring (more details in the publications).

Figure 5. Stakeholders debating about the Catalan beach systems in the 1st MS-meeting held in Barcelona on April 1st 2016. Source: Nubia Caramello.

After this, I organized and led five FGs, each based on one of the identified dimensions. These, together with an online questionnaire applied to a particular case, supported the assessment of the SL-BQI through an analysis of its basic assumptions by application of the NUSAP method, and a detailed debate of its structure. In particular,

[7] I use the term "participations" instead of "participants" because some participants attended two or more of the expanded peer review instances.

NUSAP is an abbreviation combining more quantitative types of uncertainties—Numeral, Unity, Spread—with the qualitative ones—Assessment of Reliability and Pedigree—that in practice unfold into a pedigree assessment matrix which should be qualitatively and quantitatively assessed through an open peer review (Funtowicz & Ravetz, 1990; Van der Sluijs, et al., 2003). A set of pedigree criteria integrated the matrix (Van der Sluijs, et al., 2003): influence of resource limitations, (im)plausibility, choice space, (dis) agreement among peers, analysts' objectivity, and influence on the global outcomes (further details in publication 1). On the other hand, the discussions held about the SL-BQI structure centred on its scale and sub-indexes, the available data and methods needed for the calculation of sub-indexes, and the subsequent assessment of beaches in practice, as well as the means through which I could compile the missing data.

Such an expanded peer review accounted for a DL learning process (Garnåsjordet, et al., 2012) for the (re)development of the SL-BQI, leading to its update and transformation into the DL-BQI. That is, a posterior analysis of the debates developed and recorded in the FGs supported the identification of non-correspondences between the SL-BQI sub-indexes and the expectations of the peers, which were addressed and presented in the updated DL-BQI. As to the correspondences, these were maintained in the DL-BQI. This DL-BQI was then applied to 96 beaches representative of the whole Catalan coast.

Subsequent to the assessment of Catalan beaches enabled by the DL-BQI, a second MS-meeting was organized to check the outcomes of this tool, its capacity to provide information for policy, and indirectly to also check its structure. The final considerations of the whole process served to underline the main information for policy, i.e. I organized and wrote the DL-BQI primary changes, the DL-BQI sub-indexes' results for each beach and possible groups of beaches (e.g. according to beach type), and the implications of these results for the main narratives of the Catalan coast.

5.2. Composition of the DL-BQI

The DL-BQI, as the SL-BQI (Figure 4), was structured in four levels taking the beach dimensions as a base. Clarifications regarding these terms and others are described below (Shields, et al., 2002; Peña-Alonso, 2015):

- Level of the index: Hierarchy of the index, from the most general to the most concrete level: index, groups of sub-indexes (related to the dimension/function), particular sub-indexes and the variables.
- Index (1st level): Global set of measurements used to comply with a global objective, e.g. the intended SL-BQI.
- Dimension (2nd level): One particular organization scheme of the set of sub-indexes, denoting the nature of a group of sub-indexes. For example, the recreational activity dimension comprises eight corresponding sub-indexes (i.e. microbiological water quality, beach crowding, services and facilities, conflictual activities, accessibility, waste and sewage pollution, comfort quality, and beach safety).
- Sub-index (3nd level): Particular set of measurement(s) inside the index responding to a particular objective that, when calculated, should indicate the status of what is

measured in comparison to an arbitrary standard. One example is the microbiological water quality that aims at detecting organic pollution.

- Variable[8] (4rd level): Specific asset or process measured which, alone or together with other variables, will support the identification of the particular sub-index objective. It is the minimum unity of the measurement. Continuing with the former example, the microbiological water quality comprises two variables: *Escherichia coli* and *Enterococcus intestinals*.

Weight allocation, normalization and aggregation of variables, and reporting of scores
To account for the differential importance of each variable or group of variables composing the sub-indexes, weight was assigned to them accordingly, based on the SL-BQI weight allocation and the later discussions held in the FGs. It is worth mentioning that both procedures of weight allocation and aggregation of variables are also value laden (Peña-Alonso, 2015), but the expanded peer processes particularly have supported adjustments according to justifications expressed in words. For example, in the SL-BQI sub-index, that preceded to the DL-BQI, waste and sewage pollution—i.e. the environmental quality sub-index—the same weight could be assigned to all types of waste; nevertheless, the FG on recreational quality called for a separation of scoring in the case of foam, tar, oil, and odour under the argument that these are not so common and innocuous as may be the case for human solid waste. After the weighting, the results of variables were normalized in a score ranging between 0 (poor performance) to 1 (good performance) (Ariza, et al., 2010), except for certain variables which were counted as extra points (negative or positive scores).

Aggregation of elements was practised only at the sub-index and variables levels, respecting the incommensurability existing at higher hierarchical levels of the tool (Martínez-Alier, et al., 1998). That is to say, sub-indexes refer to different non-equivalent representations of certain partial objectives, assets, and processes of beaches; thus, they cannot be compared with each other through aggregation, as this procedure would imply loss of relevant information (Martínez-Alier, et al., 1998; Giampietro & Saltelli, 2014). As a result, no overall combined score of the whole set of the DL-BQI is presented. Instead, the sub-indexes are treated separately and represented by non-aggregated alternatives, e.g. a radar diagram in which the average outcomes of each sub-index are plotted (Gomero & Giampietro, 2005). It is believed that non-aggregated types of representation may lead to more in-depth discussions before establishing relationships between sub-indexes, should these exist, and informing policy. As highlighted by Peña-Alonso (2015), each sub-index outcome allows for the identification of specific dynamics, crucial for the definition of management priorities.

5.3. Field work and techniques/methods of data collection

In pursuance of the assessment of the sustainability of beach systems of the Catalan coast, a group of 96 beaches was chosen as representative of the heterogeneity of this territory. In the following paragraphs, I introduce the combined procedures (Table 3)

[8] The term “variable” is here taken as a synonym of “attribute” (adapted from Peña-Alonso, 2015).

used to compile the data required for this assessment through the DL-BQI (more information is found in publication 3 of Chapter 2).

Table 3. Set of methods used for data collection of each DL-BQI sub-index.

DL-BQI Sub-index	Attribute/variable	Type of method used for data acquisition
Microbiological water quality	*Escherichia coli, Enterococcus intestinals*, short-term pollution episodes	Available data from the Catalan Water Agency (ACA, 2016)
Beach crowding	Density of users (user/m^2)	Own elaboration based on field trip of 2017
Waste and sewage pollution*	Short-term pollution and beach closure	Available data from the Catalan Water Agency (ACA, 2016)
	Water quality (color, transparency, solid human waste, foam, tar, oil and odor), state of entrances, sand quality (solid human waste and tar), and rainwater outfall	Own elaboration based on field trip of 2016
Services and facilities*	Beach guarding and bathing support services	Platges.cat app (ACA, n.d.)
	Wi-Fi signal	Mobile phone coverage app (Gencat, n.d.)
	Remaining variables of services (parasol and hammocks, restaurants/bars and stalls, and information), facilities (showers and footbaths, garbage cans, sanitary facilities, facilities for children, and sports facilities) and, density of services and facilities (%)	Own elaboration based on field trip of 2016
Conflictual activities	Pets, fishing during bathing hours, sailing activities in bathing areas, peddlers, sports outside specific areas, and loud music/noise	Own elaboration based on field trip of 2016
Accessibility*	Public transportation services	Platges.cat app (ACA, n.d.)
	Parking, parking fee, distance parking for beach, distance parking for disabled people, bicycle lane, bicycle parking, pavement (walking), distance between pedestrian entrances, and footbridges	Own elaboration based on field trip of 2016
Comfort quality	Weather (water temperature, % of rainy days, % of cloudy days, & of strong wind)	Consultation of the State Meteorological Agency data (AEMET)
	Jellyfish	Catalan Water Agency beach records (ACA, n.d.)
	Physical (width, slope of dry area, slope of wet area, obstacles, step, and abrasive material)	Own elaboration based on field trip of 2016
Beach safety	Human resources (supervisor, lifeguards, recreational boat keeper), surveillance point, medical emergency and first aid point, rescue boat, vehicles, signposting, communication, and sea mark	Online consultation of bidding conditions established by each municipality
Quality of surrounding area	Aesthetic quality (Impervious land use in the view shed of the beaches)	Laboratory of Landscape Analysis and Management (Department of Geography, UdG)
	Landscape quality (Impervious surface, coastal defense works against beach length, and water table enclosed by harbor and/or marine developments)	Own elaboration based on GIS (CREAF, n.d.; ICGC, n.d.)

[Continuation of Table 3]. Set of methods used for data collection of each DL-BQI sub-index.

DL-BQI Sub-index	Attribute/variable	Type of method used for data acquisition
Current conditions of dune systems	Two dune morphology parameters (dune area and dune type)	dunes.cat website (Garcia-Lozano & Pintó, n.d.)
	Other dune morphology parameters (Mean height and length of dunes, and built environment), most of human impact parameters (car parking/car tracks, density of the erosion pathway, dune breaches, invasive species and fixed dunes) and of the dune restricted plant system	Laboratory of Landscape Analysis and Management (Department of Geography, University of Girona)
	Beach raking (other human impact parameter)	Consultation with coastal municipalities
State of water bodies	Physical-chemical (Phosphates-Ammonias-Nitrites and preferred substances) ecological (*Posidonia oceanica* Multivariate Index, Phytoplankton – Chlorophyll-a concentration, Seaweeds, Macro-invertebrates) and chemical status (priority substances) of water bodies	Available data from Catalan Water Agency (ACA, n.d.)
Natural heritage	Interest in conserving the most abundant habitat of each beach	Own elaboration based on the Cartography and bibliography information of littoral habitats (Departament de Territori i Sostenibilitat, 2014a)
	Marine heritage	Own elaboration based on the Seagrass SIG (Dept. d'Agricultura, Ramaderia, Pesca i Alimentació, 2018)
	Natural protected areas	Own elaboration based on the General SIG of the Catalan Government (Gencat, n.d.)
	Geological Interest within a radius of 300m from the beach	Own elaboration based on the SIG geological interest (Dept. de Medi Ambient, 1999)
Protection	Harmful meteorological events of the last 10 years	*La Vanguardia* (La Vanguardia, n.d.) and *Diari Ara* (Diari ARA, n.d.) newspapers
Changes in physical processes	Soft engineering works developed in the last 10 years	Direct consultation with the Coastal Agency of the Spanish Ministry for the Ecological Transition
	Berm height and depth of closure for volume calculations	*Llibre verd* (CIIRC, 2010)

* Some of the data were posteriorly checked through SIG or by the platges.cat app (ACA, n.d.).

a) Field work

Two field work sessions were organized and carried out during the high season (July–August) of 2016 and 2017 (Table 4), in which a variety of tasks were implemented for the acquisition of data for some of the sub-indexes. Data was registered in a field work file and later digitized.

Table 4. Dates and tasks applied in the field trips for data collection.

Field work	Date	Tasks
1st	June 11–August 13 2016	Measurement of some variables of the sub-indexes of waste and sewage pollution, services and facilities, conflictual activities, accessibility, and comfort quality; as well as taking of support photographs
2nd	June 24¯August 12 2017	Taking photographs for the calculations of the beach crowding sub-index

In the first field trip, each of the set of 96 beaches was visited once, in which (some) variables of the **waste and sewage pollution**, **services and facilities**, **conflictual activities**, **accessibility,** and **comfort quality sub-indexes** were measured and registered. Photographs (Figure 6) were also taken in order to check future potential confusing data registered in the field work file. For example, if the information registered was blurry, using a computer I proceeded to observe the photos of the corresponding beach before digitizing the information. This helped to avoid errors in the acquisition of data due to field work procedures or conditions.

Figure 6. Taking photos of the facilities found at the *Pont del Petroli* beach, Badalona. Source: Helena Correia.

In the second field trip, 10 beaches were revisited during a whole day to take hourly photographs of users' attendance that later would support the estimations of the **beach crowding sub-index**. The recording cards from both field work sessions were then digitized.

b) *Geographic information systems (GIS)*

First, personnel from the Laboratory of Landscape Analysis and Management (Department of Geography, University of Girona) helped by providing beach systems' demarcation, used as a base for the development of GIS analyses. This group had previously worked on the digitization process of beach areas, based on the cartographic source (1:2.500) of the Cartographic Institute of Catalonia (ICGC, n.d.), using QGIS software v. 2.4 to v. 3.8. After that, I acquired GIS for the calculations of (some) variables of sub-indexes of the **quality of surrounding area, current conditions of dune systems,** and **natural heritage**, i.e. the online orthophotomap (1:2.500) made available by the Cartographic Institute of Catalonia (ICGC, n.d.), the land cover map of Catalonia 3rd edition v. 2 (2005-2007) (CREAF, n.d.), dune information (Garcia-Lozano & Pintó, n.d.), the cartography of the Catalan coastal habitats (1:1.500) (Departament de Territori i Sostenibilitat, 2014a), the information provided by the Catalan territory SIG platform (Gencat, n.d.), and the cartography on seagrass (Dept. de Medi Ambient, 1999). These last three types of data were made available by the Catalan government. These were treated using the ArcGis v. 10.6.1 or the Miramon v.8.1e. platforms.

c) Consultation of institutions, public databases, administration reports, (online) bibliographies, and newspapers

Consultation was undertaken of institutions, public databases, administration reports, (online) bibliographies, and newspapers for the calculations of all of the other remaining variables and sub-indexes. These included sub-indexes of **microbiological water quality** (ACA, 2016), **waste and sewage pollution** (ACA, 2016), **services and facilities** (Gencat, n.d.; ACA, n.d.), **accessibility sub-index** (ACA, n.d.), **comfort quality** (State Meteorological Agency AEMET; ACA, n.d.), **beach safety** (Gencat, n.d.), **quality of surrounding area** (Laboratory of Landscape Analysis and Management, Department of Geography, University of Girona), **state of water bodies** (ACA, n.d.), **current conditions of dune systems** (Laboratory of Landscape Analysis and Management, Department of Geography, University of Girona; coastal municipalities), **protection** (Diari ARA, n.d.; La Vanguardia, n.d.), and **changes in physical processes** (Coastal Agency of the Ministry for Ecological Transition; CIIRC, 2010).

5.4. Analytical tools

For all variables of all sub-indexes, a database was constructed using Excel v. 15.23.2, making possible the assignment and registration of the observed values (i.e. of variables and, further on, sub-indexes) following the DL-BQI structure (Bombana & Ariza, 2019). In particular, the GIS analyses required the use of software tools to make calculations (using the source data) of certain variables of the **quality of surrounding area** and **natural heritage** sub-indexes, before populating a database with the obtained values, contrary to the majority of sub-indexes. Excel was also used to develop other calculations regarding variables of the **comfort quality**, **changes in the physical processes** and **beach crowding** sub-indexes.

After identifying the values for each variable of all sub-indexes, scores were assigned and normalized in a range from 0 (worst performance) to 1 (best performance) (Ariza, et al., 2010), especially because the average scores of all sub-indexes were then graphically represented in a radar chart (Gomero & Giampietro, 2005) to generate a global view of the state of the Catalan coast. Statistically significant differences were analysed through the Kruskal-Wallis and Dunnett's tests in SPSS v.24 for each sub-index, taking into account different possible aggregations of beaches (i.e. by the classes of level of urban development, by Catalan provinces, and, in the case of the safety sub-index, by the level of risk).

6. LIMITATIONS OF THE APPROACH

> "None can claim that the restoration of quality through extended peer communities will occur easily, and without its own sorts of errors. But in the processes of extension of peer communities through the approach of Post-Normal Science, we can see a way forward, for science as much as for the complex problems of the environment." (Funtowicz, et al., 1999, p. 10)

Given that the PNS framework calls for the centrality of irreducible uncertainties of the scientific studies approaching complex systems (Funtowicz & Ravetz, 1993), I must reiterate that, first, this thesis intended to acknowledge and report such a fact in the case of beaches by proposing new quality methodologies to assess values and uncertainties and to enhance the building and the assessment enabled by a beach management tool designed for the Catalan beaches. Regardless of any shortcomings in the previous tool, shortcomings of a different nature are present herein. They include boundaries of different scales of analysis (e.g. individual, research group, connection with the expanded peer community), as well as my personal and professional background and time and financial limitations of the research project.

Secondly, to highlight the most important limitations of this thesis, I briefly draw on four types of uncertainty observed (Funtowicz & Ravetz, 1990; Kovacic, 2015). The first one is the most commonly reported in scientific studies, the technical uncertainty related to the expected error of measurement outcomes (traditional statistics). One example is the standard deviation of a sub-index average score for a certain beach. Second, methodological uncertainty associated with the methods applied in the representation of the observed system (i.e. the beaches) is also present. For example, the conflictual activities sub-index targeted the potential annoying activities for (some of) the beach users; this was done by observing their occurrence *in situ* at some point on an average day of summer. Uncertainty thus comes from the fact that the observer, when not at the beach, cannot identify such activities; and when the observer is at the beach, in most of the cases, it is not possible to cover the whole area due to its size. Moreover, the choice of which activities are conflicting may represent a subjective decision. Third, another type of uncertainty, at a higher level, is the epistemological uncertainty, which indicates our limited capacity of understanding the beach system. In this case, integrating different viewpoints and proposals of diverse stakeholders may contribute to the enhancement of the knowledge available for the management of beaches. Finally, beach systems are also subjected to ontological uncertainty or indeterminacy related to the characteristic of beaches as becoming systems. That is, the constant changes and emergent properties within beach systems and their relation to the observer cannot be constantly incorporated in the initially fixed problem framing for building the DL-BQI. In our case, the construction and application of the set of sub-indexes were realized in the last four years, and a potential future application would need updates to increase the quality of the respective future outcomes, given that some processes and assets may have evolved from this point onward. For example, the increase of episodes where coastal infrastructure is damaged due to increased sea level rise associated with climate emergency may need the efforts of a collective of institutions, beyond the institutions consulted in this thesis, undertaking coastal works or other strategies to protect such coastal infrastructure, so that the sub-index related to changes in physical processes would possibly need to expand its sources of information and types of works considered.

2. COMPENDIUM OF PUBLICATIONS

*For editing reasons, the description, position and numeration of the tables, figures and appendices, as well as the citation style may vary slightly between the original publications and the following transcriptions. Also, to prevent excessive repetition, the graphical scheme representing the single-looped BQI (SL-BQI) was excluded from the following sections given that it is already presented in section 5 (Practical approach) of chapter 1 (Introduction).

2.1 | CLARIFYING SOME ASSUMPTIONS OF COASTAL MANAGEMENT: ANALYSIS OF VALUES AND UNCERTAINTIES EMBEDDED IN BEACH QUALITY INDEXES

PUBLICATION 1

Bombana, B & Ariza, E. (2018). **Clarifying some assumptions of coastal management: Analysis of values and uncertainties embedded in beach quality indexes.** Ecological Indicators, 91, 376-385.

ELSEVIER

Ecological Indicators
Volume 91, August 2018, Pages 376-385

Original Articles

Clarifying some assumptions of coastal management: Analysis of values and uncertainties embedded in beach quality indexes

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Highlights

- A knowledge assessment highlighted the main weaknesses of scientific beach management tools.
- The beach indexes' structure is dissociated from their theoretic discourse on complex systems.
- A focus on beach user satisfaction prevails, minimizing other management objectives.
- The analysis of beaches calls for an opening up and contextualization of scientific knowledge.

ABSTRACT

For the first time, this research addresses the assessment of the quality of knowledge embedded in beach quality indexes from a socioecological perspective. We took the most widespread beach quality indexes and identified, selected and assessed the most important existing assumptions. We scored the robustness of these assumptions, using an inclusive methodology (stakeholder meeting, four focus groups and an online questionnaire). The NUSAP criteria for assessing the value-ladenness of scientific studies (Influence of resource limitations, (Im)Plausibility, Choice space, Agreement among peers, Analysts' subjectivity and Influence on global results) were contrasted and discussed. A final list of the 10 weakest assumptions was presented and discussed. Most of these assumptions are fairly robust, but attention should mainly focus on their influence on global outcomes and (im)plausibility, as the weakest scored criteria. The choice space scores revealed the possibility of including new alternatives to the assumptions, when necessary. Assumptions loaded with framing concepts are weaker than those linked to more concrete objectives. We detected dissociation between the discourse and the operational development of the indexes, in which the narratives prioritizing user satisfaction are predominant and scientific data analysis is often decontextualized. We therefore suggest that science should be opened up throughout the building process of indexes: from the identification of problems to the reporting of results and related uncertainties. The NUSAP method proved to be useful for identifying weak points in beach quality indexes.

Keywords: Coastal management; beach indexes; knowledge assessment; scientific assumptions; uncertainties; complexity.

1. INTRODUCTION

The analysis of beaches as socioecological systems (SES) (e.g. (Defeo & McLachlan, 2005; Botero & Hurtado, 2009)) has been developed only in recent years, following almost three decades of use of analysis and ranking tools, that, despite contributing to this body of knowledge, failed to truly address the existing complexity of these systems (Ariza, et al., 2008a). Although traditionally claimed to be an objective process, the choice of which components and interactions are needed to understand the behaviour of SES is biased by scientists' values, interests and background (Rosen, 1993; Sarewitz, 2004; Bremer & Glavovic, 2013a). Doing science for policy involves a number of renounces. In this way, approaches to the management of beach SES have traditionally focused on a very limited number of functions, such as beaches as summer playgrounds and buffer spaces for storms (James, 2000; Lozoya, et al., 2014; Ariza, et al., 2016). The process has prioritized specific narratives over others, resulting in a lack of scrutiny of the overall functioning of the system.

The assessment presented here takes and explores the potential contribution of the Post Normal Science (PNS) - a guiding epistemological perspective that emphasizes the high stakes and uncertainties involved in socioecological problems and alternatives (Funtowicz & Ravetz, 1993) - to beach management, by highlighting the enclosed narratives and contexts. In practical terms, we critically assessed the knowledge embedded in the existing beach quality indexes. We started the analysis with the BQI (see section 2) and expanded it to 5 other well-known beach quality indexes, through the identification, screening and evaluation of their scientific assumptions. In order to do this, we applied one of the operational PNS tools: the NUSAP method.

2. BACKGROUND OF BEACH QUALITY INDEXES AND THE EPISTEMOLOGICAL FRAMEWORK

2.1. The evolution of beach management tools

A consolidated line of research on beaches has led to the development of management practices and tools. In the first book dedicated to the topic, beach management is defined as a "subset of coastal management but with particular reference to pragmatic local management" (Williams & Micallef, 2009). Here, awards, rating schemes and sets of indicators to measure beach performance have been identified since 1985, when the Blue Flag rating scheme was developed as a response from the tourism industry to the crisis of mass tourism and its subsequent impacts on natural resources (Fraguell, et al., 2013).

After the Blue Flag rating scheme, different initiatives began to appear in different countries (e.g. (Leatherman, 1997; Morgan, 1999)), designed to support costal leisure activity on beaches, accounting, in a very limited way, for environmental aspects (Williams & Micallef, 2009). Most importantly, they represented beaches as a static photograph rather than a dynamic system, since their usual methodology consisted of fulfilling a list of requirements for beach performance (e.g. (Mir-Gual, et al., 2015)) ranking "where the 'best beaches' occur" (Williams & Micallef, 2009), most of them regardless of socioecological specificities and interactions.

In the late 1990s, the latest advances in sustainability research proposing more systemic approaches, i.e. Environmental Management Systems (EMS) (Seiffert, 2009), started to converge with the research on beach management (Yepes, et al., 1999). This led to a more integrative process through the inclusion of different stakeholders in the analysis and decision-making, as is the case of the Spanish UNE-EN ISO 14.001 standard (Williams & Micallef, 2009). Nonetheless, quality standards were limited in their coverage of socioecological beach systems due to their vocation towards market competitiveness in the tourism sector (Yepes, 2005).

The new century brought a turning point, when beaches were expressly defined as socioecological systems and the ecosystem-based management approach was included in the conceptual framework of the field (Ariza, et al., 2008a). Since then, scientists have proposed that natural beach assets should be better incorporated into classical certification schemes (Lucrezi, et al., 2015; Fraguell, et al., 2016) and especially new methodologies for capturing beach complexity in order to provide information for sustainable management (Cervantes & Espejel, 2008; Ariza, et al., 2010; Botero, et al., 2015; Todd & Bowa, 2016; Lucrezi, et al., 2016; Semeoshenkova, et al., 2017).

The Beach Quality Index (BQI) (Ariza, et al., 2010; Ariza, et al., 2012) was the first index designed to cater for different beach systems and functions in an integrated framework (Williams & Micallef, 2009). Hierarchically organized in four levels, the first corresponds to the overall tool, the second to the three beach functions identified (natural, protective and recreational), followed by a third level composed of 13 sub-indexes, which finally deploy the corresponding measurement variables (fourth level).

2.2. The uncertainty assessment

The methodologies developed to date for capturing beaches as multidimensional systems (more in Table 5) have included non-academic narratives in a limited way, i.e. only beach users' perceptions. They did not consider uncertainty multidimensional assessment during the index building process (Walker, et al., 2003), and did not include checks of their usefulness as a guide for political decisions on beach matters.

The PNS, more than an epistemological guide, seeks to bring the uncertainties of contemporary complex problems to the centre of academic studies (Funtowicz & Ravetz, 1990). It offers an alternative for analysing and diagnosing uncertainties: the NUSAP method (Figure 7). NUSAP is an acronym for Numeral and Unity (traditional statistical approach), extended to the dimensions of Spread (uncertainty and inexactness), Assessment of reliability (methodological) and Pedigree (quality of the production process, epistemological frameworks), in such a way that the value-ladenness of academic assessments can be highlighted (Van der Sluijs, et al., 2003).

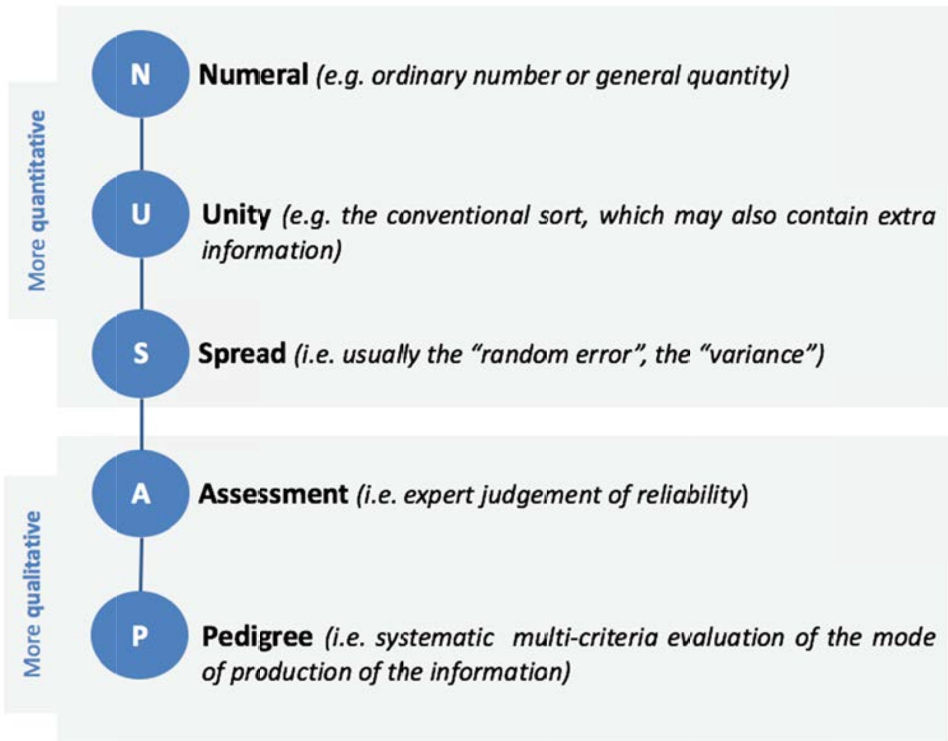

Figure 7. The dimensions of uncertainty, assessed by the NUSAP method. Adapted from Funtowicz & Ravetz (1990) and Van der Sluijs, et al. (2003).

The NUSAP can be deployed by a pedigree assessment matrix, which may take different forms (e.g. (Van der Sluijs, et al., 2003; Kloprogge, et al., 2011; Laes, et al., 2011)) through a set of pedigree criteria, such as analyst's objectivity and (dis)agreement among peers about the knowledge base. That used in Van der Sluijs and Wardekker (2015) has been adapted for this work (further details below) and represents a quali-quantitative structural process for assessing the assumptions, numbers and theories behind the available knowledge.

When Mayumi & Giampietro (2006) discussed the four sources of uncertainties presented by Knight (1964) – perception, anticipation, effect and implementation – they selected the first one as crucial for the PNS. The perception and further representation of our surrounding 'reality' is constrained by certain limitations, according to which, facts should be addressed taking into account the means used to put a shared question into perspective. In this regard, the treatment of the strength property is the most innovative part of the NUSAP method, since it is a way of reacting to the perception uncertainty, especially due to the focus on evaluating the process of information production (Ravetz & Funtowicz, n.d.). To date, the NUSAP method has not been used for the analysis of beach SES narratives and assumptions and their associated uncertainties. Therefore, the present research will provide a new methodological and analytical contribution to the field, by approaching the epistemological challenge of beach complexity and beach quality indexes.

3. METHODS

The identification of indexes of beach sustainability was performed through a Scopus search using the terms "beach" and "indexes". Those approaching the beach as a multidimensional system (Table 5) were selected.

Table 5. Reference, main objective and design of the beach indexes.

Index	Authors	Main objective and Index design
Beach Quality Index (BQI)	Ariza *et al.* (2010, 2012)	Assesses the quality of urban and semi-urban beaches, which weights and enables a comparison between three sets of sub-indexes. Each of these corresponds to one of the three beach functions: recreational, protective and natural. In addition, economic valuations were carried out.
Integrated Beach Evaluation Index (IBVI)	Cervantes & Espejel (2008)	Evaluates the quality of recreational sandy urban beaches through the weighting of a set of sub-indexes, divided into recreational capacity, opinion and attitude of users, and monetary sub-indexes.
Index of Environmental Quality in Tourist Beaches (ICAPTU, Spanish acronym)	Botero *et al.* (2015)	Assesses beach environmental quality by means of the ecosystem, sanitary and recreational quality of beaches.
Semeoshenkova *et al.* Index	Semeoshenkova *et al.* (2015)	Assesses the quality of beaches by analyzing environmental quality, human welfare and wealth.
Beach Health Index (BHI)	Todd & Bowra (2016)	Analyzes the health of oceanic beaches, by studying the functions of beaches emphasized by the BQI.
Beach Evaluation Index (BEI)	Lucrezi *et al.* (2016)	Evaluates sandy beaches through a set of indicators: beach description (recreation and management), human dimension (attitude and opinion of beach users) and monetary calculations.

The knowledge assessment of the abovementioned indexes was conducted through a methodological set delineated hereinafter, as it was approached chronologically.

Twenty-five main assumptions (Appendix A) were identified and scored. We identified/tested "in situ", with the support of stakeholders of the Catalan coast, assumptions 2, and 7 to 25, of Appendix A, which belong to the BQI (developed for the Catalan coast). The assessment was, thus, extended to assumptions of the rest of the selected indexes (assumptions 1 to 6 of Appendix A). Later in the present article, we discuss the ten weakest assumptions resulting from the whole process.

3.1. Pre-identification of assumptions: Highlighting of dimensions and narratives of the Catalan coast

A multi-stakeholder meeting was held in Barcelona on April 1st 2016, to co-define beach management dimensions, narratives and priorities of the Catalan coast. Present at the meeting were fifty-seven stakeholders from the three levels of government (i.e. state, regional and municipal), the private sector (e.g. consulting firms and certification organizations), academic institutions, the organized civil society (e.g. citizens' platforms for the environment) and a combination of the aforesaid types (e.g. clusters for the development of nautical activities). It was the first known attempt at integrating the organized civil society on the scale of Catalonia. In a joint manner, the assistants highlighted and discussed the most prominent coastal issues. By adapting the Participative Planning and Associate Management methodology (Poggiese, 1993), the meeting identified:

a) Dimensions composing the Catalan beach SES

Following Munda (2005), for this research, dimensions were conceptualized as a level of analysis broad enough to display specific objectives, indicators and variables. Dimensions comprise one or more BQI functions and elements. For instance, the morphodynamics dimension includes the protection function of beaches, but also other elements, such as sediment transport.

Beach SES dimensions in the Catalan coast are: 1. Recreational activity, 2. Morphodynamics, 3. Ecology and natural heritage, 4. Beach economics, and 5. Governance and management. Due to the complexity of this last dimension, which would require more in-depth analysis, we decided not to directly explore it in this study.

b) Narratives of the Catalan coast

Differences in societal values, perspectives and interests are manifested through narratives, i.e. the 'story' explaining them (Garnåsjordet, et al., 2012). The objective(s) of any study related to management, as is the case of the assessment tools, is the reflection of the narrative(s) being taken into account. Thus, when characterized, narratives support the identification of biases underlying the beach indexes. For the Catalan coast, the following were delineated as prevalent (Molina, 2016):

1. *Economic growth:* Beaches are a resource for tourism and leisure;
2. *Sustainable development:* Beaches are natural and public spaces. Tourism is one of the main economic activities of the coast. There is a need for regulations, social inclusion and environmental protection;

3. *Integrated coastal zone management:* Beaches are a natural space. Management is too focused on tourism services and facilities. There is a need for integrative principles and a systemic view;
4. *Environmental protection:* Beaches are natural spaces of great ecological importance. It is essential to protect the coastal zone, especially because only a few areas are not highly impacted by human activities.

The different process and relations occurring inside and between one or more dimensions were explained by the stakeholders using one or more narrative(s), i.e. these are distributed transversally across the dimensions (Molina, 2016).

3.2. Identification and assessment of assumptions

The authors compiled a list of twenty-five main assumptions (Appendix A) by contrasting the processes of creation on the selected indexes with the aforesaid analysis and the literature on socioecological indicators (e.g. (Martínez-Alier, et al., 1998; Munda, 2005; Garnåsjordet, et al., 2012; Giampietro & Saltelli, 2014)). Since our first motivation was to verify if beaches were truly approached as SES, the search for assumptions focused on the partiality of the conceptualizations - pre-analytical choices (Kovacic, 2015) - behind the structure of the beach quality indexes.

Scientific assumptions may connect different related concepts, as seen in Van der Sluijs and Wardekker (2015), so making assumptions explicit may reduce the bias of assessments, increase the quality of the knowledge base and improve uncertainty assessment (Kloprogge, et al., 2011). It is worth mentioning, though, that authors building the assumptions may also display particular limits of knowledge and perspectives (Kloprogge, et al., 2011). To minimize the arbitrariness and subjectivity of qualitative expert judgement (Van der Sluijs, et al., 2003), in this study, assumptions were assessed through the criteria displayed in the pedigree matrix of Table 6, according to which scores could be identified within a weakness range of 0 (low) to 4 (high).

Table 6. Pedigree assessment matrix. Adapted from Van der Sluijs and Wardekker (2015).

	Low weakness ←			→ High weakness
Score	**0**	**1**	**2**	**3**	**4**
Influence of resource limitations	No such limitations	Barely influenced	Moderately influenced	Importantly influenced	Completely influenced
(Im)Plausibility	Very plausible	Plausible	Acceptable	Barely plausible	Fictive or speculative
Choice space	No alternatives available	Very limited number of alternatives	Small number of alternatives	Average number of alternatives	Very wide choice of alternatives
(Dis)Agreement among peers	Complete agreement	High degree of agreement	Competing schools	Low degree of agreement (embryonic stage)	Low degree of agreement (controversial)
Analyst's objectivity	Not sensitive	Barely sensitive	Moderately sensitive	Highly sensitive	Very highly sensitive

[Continuation of Table 6]. Pedigree assessment matrix. Adapted from Van der Sluijs and Wardekker (2015).

	Low weakness				High weakness
Score	**0**	**1**	**2**	**3**	**4**
Influence on the global outcomes of the dimension(s) in question	Little or no influence	Local impact on the calculations	Important impact on a major step in the calculation	Moderate impact on end result	Important impact on end result

The pedigree criterions (Van der Sluijs & Wardekker, 2015) are:

• Influence of resource limitations: This evaluates whether the assumption has been included because of resource limitations (such as data, money, time, software, human resources, etc.). Without these, the analyst would have incorporated a different assumption.

• (Im) Plausibility: This values the level of agreement, mostly based on an (intuitive) assessment, between the assumption and the `reality' observed.

• Choice space: This analyzes the number of alternative assumptions available beyond the assumption chosen. In general, one can say that a larger choice space makes the analyst's preferences more arbitrary.

• (Dis)Agreement among peers: The agreement or disagreement of the peers in this body of knowledge is valued in the selection of the assumption. This may vary in the different bodies of knowledge.

• Analyst's objectivity: This analyzes the extent to which the assumption can be influenced, consciously or unconsciously, by the preferences of the analyst: views, interests, cultural background, discipline and personal.

• Influence on the global outcomes of the dimension(s) in question: This evaluates the impact that the choice of the assumption could have on the end result of the dimension in question.

3.2.1. The case of Catalonia: Assessment of the BQI assumptions

From the twenty-five list, those assumptions related to the BQI (assumptions 2, and 7 to 25) were tested "*in situ*" (by Catalan coastal stakeholders), before the identification and scoring of assumptions present in all selected indexes. The aforesaid test was performed by focus groups (FGs) and one online questionnaire, applying the pedigree matrix (Table 6) in an extended peer review process. This review process also checked the influence of the present authors' particular biases (Kloprogge, et al., 2011), by an initial assessment, in each FG, of the written assumptions.

a) The development of the focus groups

We organized and carried out four FGs (Table 7), each of them corresponding to the beach dimensions identified at the multi-stakeholder meeting which, in turn, are explained by one or more narratives (right column of Table 7). In total, 24 representatives of different institutions attended the meetings, satisfying requirements on FGs methodologies (Bryman, 2012). First, the BQI sub-indexes related to the specific FG subject were presented. Second, we reviewed the writing of the corresponding assumptions by reading and discussing them in a joint manner. Finally, we combed the assumptions through the application of the pedigree matrix.

Table 7. Structure of the FGs regarding the sub-indexes and narratives approached, and the number and profile of the participants.

FG	Corresponding sub-indexes	Participants		Main narratives approached
		Nº	Main profiles	
Recreational activity	Microbiological water quality*, Beach crowding, Environmental quality, Services and facilities, Activities, Access and parking, Comfort quality and Beach Safety	6	**Academic peers:** 1 Social perception expert, 2 Coastal tourism and leisure experts, 1 Integrated beach management expert **Local government:** 1 Decision maker on environmental affairs, 1 Specialist in reduced mobility	Economic growth
Ecology and natural heritage	Quality of surrounding area, the Natural conditions and the Water body ecological and chemical status*	5	**Academic peers:** 1 Integrated beach management expert, 1 Coastal geography expert **Regional administration:** 1 Specialist in Landscape planning **Consulting company:** 1 Coastal information maker and user **Organized civil society:** 1 Environmental protection activist	Environmental protection, Integrated coastal zone management
Morpho-dynamics	Physical Quality and Protection	6	**Academic peers:** 2 Coastal geology experts, 1 Coastal engineering expert **State administration:** 2 Specialists in Coastal engineering **Consulting company:** 1 Specialist in beach restoration	Economic growth, Sustainable development
Economics	Economic valuation methods available, specifically the Travel Cost Method and the Hedonic Prices	7	**Academic peers:** 1 Economic geography expert, 1 Coastal geography expert, 1 Integrated beach management expert, 1 Sustainability expert, 1 Tourism economy expert, 1 Coastal economy expert, 1 Information systems expert	Economic growth, sustainable development and Integrated coastal zone management

* As previewed by the BQI, the Microbiological water quality Index and the Water body ecological and chemical status Index (before called the Water-sand pollution Index) are updated to the new EU requirements, respectively, the Directive 2006/7/EC and the Directive 2000/60/EC.

b) Online questionnaires

An online survey (in www.surveymonkey.com) was used as a complementary tool to test the assumptions of the ecology and natural heritage dimension, i.e. assumptions 2, 16, 17, 18 and 19 of Appendix A. Four experts evaluated these assumptions using the pedigree matrix. Concomitantly, they were asked to comment on the identification and writing of the beach assumptions.

3.2.2. Expansion of the Catalan test: Review, comparison and highlighting of assumptions

The procedures followed to assess assumptions of the BQI enabled the authors to finally specify the assumptions related to all beach quality indexes considered (assumptions 1 to 6 in Appendix A), to which they also inferred pedigree scores (application of Table 6). These assumptions were identified, written and scored by the authors of the research. This process served to start a broad discussion about the quality of knowledge produced in the field of beach assessment tools.

Due to differences in the subjects approached and in the scoring given by each group of stakeholders, we reviewed and homologated the pedigree scores deployed for both the BQI and all indexes' assumptions. It served to establish comparisons between assumptions and, especially, highlight the ten weakest ones, i.e. those presenting the higher scores on the average pedigree and the influence on global outcomes criteria. We focused our discussion on these ten weakest assumptions. In order to clarify this, we present a scoring table (Table 8) and diagram (Figure 8) in the next section.

4. RESULTS AND DISCUSSION

4.1. Robustness of the indexes

Table 8 presents the scores assigned to the ten weakest assumptions. They were revealed to be somewhat robust (average pedigree score is 1.6 out of 4). The most important weaknesses were detected, respectively, for (im)plausibility (2.3), choice space (2), the analysts' objectivity (1.8), (dis)agreement between peers (1.8) and the influence on resource limitations (1.5). The influence on global outcomes, though analysed aside, presented the highest score (2.6).

4.1.1. Individual analysis of key assumptions

I - The observation (and measurement) of the processes related to recreational activities, natural heritage and ecology, and the morphodynamics of beaches are sufficient for analysing the sustainability of these SES

The management tools analysed presented sub-indexes corresponding predominantly to the dimensions of recreational activities, natural heritage and morphodynamics, marginalizing others, such as those highlighted by the multi-stakeholder participatory meeting or by some of the indexes (e.g. the BEI, BQI, BHI and IBVI of Table 5), i.e. the dimensions of beach economics, integrated management-governance, and culture and religion-spirituality. Our case experience showed that the beach SES would be better understood if indexes also accounted for the marginalized dimensions, by addressing their explanatory narratives and transforming into new sub-indexes (with particular objectives). In other words, a more holistic view of the beach is needed.

II - Specific characteristics such as the type of beach sediment, the form of the beach, the degree of urbanization and the type of residence in its surroundings do not influence the processes of the beach SES

In spite of the partial recognition by those who developed the studied indexes of the influence of specific beach characteristics on the SES elements or processes, the majority of their sub-indexes did not include variables to address it. Exceptions are found in the sub-indexes of services and facilities (in the BQI, the index by Semeoshova, et al., and the BHI), which account for the degree of urbanization in beach surroundings. If sub-indexes do not differentiate the characteristics (local specificities) needed for a robust evaluation, the state of the different beach elements or processes is not properly assessed. Resource limitations demand prioritization of those most relevant for each sub-index. For example, the degree of urbanization, while central to services and facilities, would not directly influence user comfort, which includes aspects of the beach structure (e.g. slope, width) and climatic conditions.

III - Beach user satisfaction is the main objective of beach studies

Beach user satisfaction, supported by those narratives corresponding to tourism and leisure (economic growth and partially sustainable development; Molina, 2016), seems to prevail over other beach management objectives in all indexes. In the BQI, the sub-indexes corresponding to the recreational activity dimension are predominant. Even when sub-indexes for the dimensions of morphodynamics and natural heritage and ecology are included, this is done with the aim of promoting certain types of recreation. For instance, variables for measuring litter management are especially focused on the potential impacts on users' perception, rather than other impacts more linked with the overall SES. It is worth mentioning, though, that this assumption would increase in plausibility when the focus of studies is on those beaches with higher levels of urbanization and usually with more services and facilities (Lozoya, et al., 2014).

As recognized by the authors of the indexes (Cervantes & Espejel, 2008; Ariza, et al., 2010; Botero, et al., 2015; Lucrezi, et al., 2016; Todd & Bowa, 2016; Semeoshenkova, et al., 2017), these were mainly built for recreational beaches, emphasizing a preference towards beach user satisfaction. However, the constraint of the analysis to only one objective (i.e. promote user satisfaction) will not adequately explain the complexity of the beach processes and interrelations. Socioecological processes occurring on beaches do not cease just because these are mainly managed as recreational spaces, thus sub-indexes responding to other SES processes rather than recreational activity should also be included. This assumption obstructs more integrated and collective conceptualizations (Bremer, 2013; Garnåsjordet, et al., 2012), maintaining the reductionist view of the beach as a merely recreational space (James, 2000; Lozoya, et al., 2014).

IV - The different processes of the beach SES are commensurable

The analysed tools make use of weighting and aggregating procedures (i.e. a calculation chain) in order to establish a single result, expressed by a number or evaluation class, and only rudimentarily deal with their embedded inexactness. Though the indexes sought to value the different non-equivalent representations of beaches (Kovacic, 2015), they assume that different assets, processes and interrelations can be compared and weighted in the same way, inadequately translating them into the practical sub-indexes and variables. In other words, they assume commensurability (Martínez-Alier, et al., 1998).

Table 8. Pedigree score of the selected assumptions.

Assumptions		*Influence of resource limitations*	*(Im) Plausibility*	*Choice space*	*(Dis) Agreement among peers*	*Analyst's objectivity*	*Average pedigree score*	*Influence on the global outcomes of the dimension in question*
I	The observation (and measurement) of the processes related to the recreational activities, the natural heritage and ecology, and the morphodynamics of beaches are sufficient for analyzing the sustainability of these SES	2 (Moderately influenced)	2.5 (Accepta-ble to barely plausible)	3 (Average number of alterna-tives)	2 (Competing schools)	3.5 (Highly to very highly sensitive)	2.2	4 (Important impact on end result)
II	Specific characteristics such as the type of sediment of the beach, the form of the beach, the degree of urbanization and the type of residence in its surroundings do not influence the processes of the beach SES	2.5 (Moderately to importantly influenced)	4 (Fictive or specula-tive)	3 (Average number of alterna-tives)	1 (High degree of agree-ment)	1.5 (Barely to moderately sensitive)	2	4 (Important impact on end result)
III	Beach user satisfaction is the main objective of beach SES studies	1 (No such limitations)	2.5 (Acceptabl e to barely plausible)	2.5 (Small to average number of alternatives)	4 (Low degree of agreement (controversial))	3 (Highly sensitive)	2.2	4 (Important impact on end result)
IV	The different processes of the beach SES are commensurable	1.5 (Barely to moderately influenced)	4 (Fictive or specula-tive)	2 (Small number of alterna-tives)	4 (Low degree of agreement (controversial))	2.5 (Moderately to highly sensitive)	2.3	4 (Important impact on end result)
Average score (I to IV)		**1.8**	**3.3**	**2.6**	**2.8**	**2.6**	**2.2**	**4**

[Continuation of Table 8]. Pedigree score of the selected assumptions.

	Assumptions	*Influence of resource limitations*	*(Im) Plausibility*	*Choice space*	*(Dis) Agreement among peers*	*Analyst's objectivity*	*Average pedigree score*	*Influence on the global outcomes of the dimension in question*
V	The evaluation of the surrounding quality (hinterland artificialization in a 500m strip around the beach and in a strip of 200 m offshore from the emerged beach), of the state of natural conditions in the emerged beach part and the ecological, physicochemical and chemical state of the water masses provide an adequate measure for the management of ecology and the natural heritage of Catalan beaches	2 (Moderately influenced)	1.5 (Plausible to accepta-ble)	2 (Small number of alterna-tives)	2 (Competing schools)	2.5 (Moderately to highly sensitive)	1.17	3 (Moderate impact on end result)
VI	The monitoring of the state (and potential) of the dune system is adequate and sufficient to determine the natural heritage of the emerged part of Catalan beaches. This state (and potential) is determined by the numerical evaluation of the presence of typical dune system flora species in Catalonia, the extension of the dune vegetation area in relation to the wind controlled part of the beach and the visual assessment of the dimension of the habitat	3 (Importantly influenced)	2.5 (Accep-table to barely plausible)	3 (Average number of alternatives)	2 (Competing schools)	1.5 (Barely to moderately sensitive)	2	2 (Important impact on a major step of the calculation)

[Continuation of Table 8]. Pedigree score of the selected assumptions.

	Assumptions	*Influence of resource limitations*	*(Im) Plausibility*	*Choice space*	*(Dis) Agreement among peers*	*Analyst's objectivity*	*Average pedigree score*	*Influence on the global outcomes of the dimension in question*
VII	Beach morphodynamics should be assessed by analyzing beach capacity for coastal protection and human impacts on beach physical structure	1 (No such limitations)	2 (Accepta-ble)	2 (Small number of alterna-tives)	2 (Competing schools)	2.5 (Moderately to highly sensitive)	1.6	3 (Moderate impact on end result)
VIII	The effective width of the beach, the storm reach and the minimum width of the beach enable a good representation of the capacity of beaches for coastal protection. The use of the *SBeach* model is adequate to calculate beach protection capacity on Catalan beaches	2.5 (Moderately to importan-tly influen-ced)	2.5 (Accepta-ble to barely plausible)	2 (Small number of alterna-tives)	2 (Competing schools)	1 (Barely sensitive)	1.7	2 (Important impact on a major step of the calculation)
IX	The anthropogenic impacts on the physical quality of beaches can be identified by the changes in grain size, beach surface and wave regime	2 (Moderately influenced)	2.5 (Accepta-ble to barely plausible)	1 (Very limited number of alternatives)	1 (High degree of agreement)	1 (Barely sensitive)	1.3	2 (Important impact on a major step of the calculation)
X	All values of beaches can be expressed in monetary terms	1 (No such limitations)	4 (Fictive or specula-tive)	3 (Average number of alternatives)	2 (Competing schools)	3 (Highly sensitive)	2.2	3 (Moderate impact on end result)
Average score (V to X)		**1.9**	**2.5**	**2.2**	**1.8**	**1.9**	**2.6**	**2.5**
Average total score (I to X)		**1.5**	**2.3**	**2**	**1.8**	**1.8**	**1.6**	**2.6**

Criticism regarding composite indexes, especially by some ecological economists, highlight that different non-equivalent representations of beaches cannot be reduced without the loss of relevant information and an inevitable conflict between narratives (Martínez-Alier, et al., 1998; Munda, 2004; Giampietro & Saltelli, 2014). More time and new participatory tools and methods would be needed to better consider non-equivalent representations of the beach, but a shift to an incommensurable logic is the main priority in this direction. For example, the index by Semeoshenkova, et al. (2015), despite using weighting (i.e. ranking the sub-indexes and variables) and a linear aggregation, has displayed the results through a radar chart that highlights the different dimensions analysed.

V -The evaluation of the surrounding quality (hinterland artificialization in a 500m strip around the beach and in a strip of 200 m offshore from the emerged beach) of the state of natural conditions in the emerged beach part and the ecological, physicochemical and chemical state of the water masses provide an adequate measure for the management of ecology and the natural heritage of Catalan beaches

Although the sub-indexes of surrounding quality, natural conditions, and state of water masses encompass the main ecological/natural heritage processes occurring in the beach, part of its natural assets may be overlooked. In the case of Catalonia, suggestions for a more complete analysis of the dimension in question included sub-indexes for the measurement of geological values (e.g. ancient dunes), species of fauna (e.g. *Charadrius alexandrinus*) and submerged beach heritage (e.g. Mediterranean marine biogenic constructions).

VI -The monitoring of the state (and potential) of the dune system is adequate and sufficient to determine the natural heritage of the emerged part of Catalan beaches. This state (and potential) is determined by the numerical evaluation of the presence of typical dune system flora species in Catalonia, the extension of the dune vegetation in relation to the wind controlled part of the beach and the visual assessment of the dimension of the habitat

In the analysis of the ecology and natural heritage dimension (emerged part of the beach), it is assumed that its assessment would be sufficiently carried out through the monitoring of the aforesaid characteristics of the state of dune systems in Catalonia. Nonetheless, not all Catalan beaches have the potential for hosting natural dunes (Pintó, et al., 2014). As observed by one of the respondents to the questionnaire: "sandy areas with coarser materials (that never form dune belts and, consequently, never deploy species of dune flora) may present a low conservation value despite being well preserved". A better adapted measurement to the Catalan context would value other assets of the emerged part of beaches, considering a wider range of beach types (not just those with potential dune systems). The observation of vegetation species other than those of dunes, as well as cliffs and communities of invertebrates has been discussed.

VII - Beach morphodynamics should be assessed by analysing beach capacity for coastal protection and human impacts on beach physical structure

The observation of other assets/processes besides capacity for coastal protection and human impacts on the physical structure would contribute to a wider view of the beach morphodynamics dimension. Some examples of these assets/process are those contributing toward coastal evolution (e.g. changing beach forms and, ultimately, coastal geomorphological features) and water filtration (by pressure changes in the bed of surf zones). Part of the bias given by the assumption relates to the usual prominence given to the protection function in beach management tools (James, 2000).

VIII -The effective width of the beach, the storm reach and the minimum width of the beach enable a good representation of the capacity of beaches for coastal protection. The use of the SBeach model is adequate to calculate beach protection capacity on Catalan beaches

The first factors that weaken this assumption's plausibility are the limitations of the model, *SBeach*, which estimates beach protection capacity through the calculation of the effective width of the beach, the storm reach and the minimum width of the beach. This model (Larson & Kraus 1989 in Thieler, et al., 2000) was designed to predict beach and dune erosion caused by storms, and also the formation and movement of bars. It, then, assumes beach dynamics as a 1D process (cross-shore movement due to waves), despite being a 3D reality; no net loss or gain of sediments; and uniform longshore process (i.e. they are not considered) (Thieler, et al., 2000) In addition, the model requires a calibration process in order to be applied in the study area, which is not usually carried out.

This assumption also excludes important conditions that decisively affect coastal protection, such as the height of the aerial part of sandy beaches and the beach rotation occurring in pocket beaches, as occurs in a significant part of the Catalan coast. The main alternative to this would be to carry out an analysis of the coastline evolution for each beach, enabling the identification of erosion/accretion trends. This, instead of estimating the effective width of the beach, the storm reach and the minimum width of the beach, would account for the identification of rates of coastline movement, which would indicate the potential of beaches for coastal protection. Other technical and methodological uncertainties would be embedded in this new alternative; nonetheless, it may reduce the demand for resources and include pocket beaches, making it a better-suited measurement for the Catalan reality.

IX - The anthropogenic impacts on the physical quality of beaches can be identified by the changes in grain size, beach surface and wave regime

The BQI assumes that non-anthropogenic (natural) processes are not capable of changing grain size, beach surface or wave regime. However, natural dynamics would also account for such changes in some coastal areas; for example, grain size may vary in beaches surrounding river mouths. Rivers are a transport agent contributing with sediments of variable grain size. In this sense, the present assumption may potentially mislead the estimation of anthropogenic impacts. As an alternative for calculating the anthropogenic impacts, a suggestion is made to directly check the existence of previous interventions (official engineering works) undertaken on the coastline (e.g. beach nourishment). Uncertainties regarding this method were emphasized, such as the non-identification of non-official sand nourishments; however it would decrease the demand of resources for the analysis.

X - All beach values can be expressed in monetary terms
All the economic valuation methods applied in the IBVI, BQI and BEI - the travel cost method (TCM)/ hedonic pricing (HP) - are supported by the assumption in question, which is epistemological, grounded in the field of environmental economics. All beach values can be expressed in monetary terms, i.e. they are commensurate. In contrast, the ecological economics approach stands for the analysis of the socioecological systems through a plural framework, rather than trusting exclusively in monetary valuations, assuming the incommensurability of values and considering the complex relationships of SES.

Questions such as "Is it possible to put a monetary term on a particular species or process, which can deploy a variety of other values?" are highlighted (Funtowicz & Ravetz, 1994). Alternative suggestions to this assumption would entail a wider set of economic and non-economic valuations, such as multicriteria frameworks (Munda, 2005). Though this would possibly involve more resources, we infer that the election of this assumption is much more influenced by the pre-analytical choice for a certain conceptualization of beach valuations.

4.1.2. Final assessment of the key assumptions

The average pedigree score of each assumption was plotted against the results for influence on the global outcomes' criterion (Figure 8; as in Kloprogge, et al., 2011) in order to group the most critical ones. From the list of ten assumptions, six are placed in the bottom-left corner of the graph, demarcated by the light red area where both the average pedigree and the influence of results are >= to 2, corresponding to the "weakest quadrant".

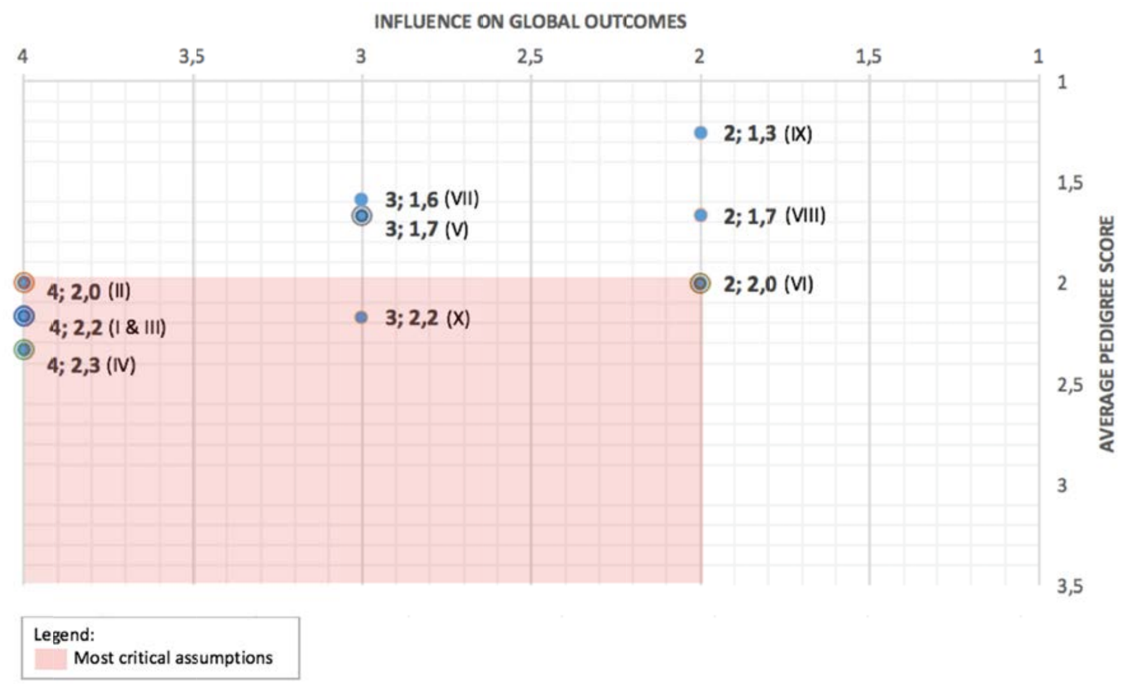

Figure 8. Diagnostic Diagram for the pedigree score of index assumptions: Those located in the bottom-left corner are the most critical. For better visualization, the scale of the axes does not correspond to that of the criteria (0 to 4). Source: Own elaboration.

Following the aforementioned graphical representation, we summarized what we found to be the most important aspects of each criterion analysed, posing some examples of individual assumptions. The group of assumptions related to all indexes (I to IV) presented the highest average scores (high weakness) for all criteria in comparison with the assumptions strictly of the BQI (V to X), except for assumption X. This difference seems to be linked with a higher conceptual (and abstract) load of all indexes' assumptions, which are responsible for defining the way sub-indexes are framed to represent the beach SES. The other assumptions (from the BQI) refer to more concrete questions and objectives.

In particular, the highest scores for the influence on the global outcomes criterion correspond to assumptions located in the highest hierarchy of the indexes (first or second level of the BQI hierarchy), and may be found in all indexes selected. Moreover, for example, assumption IX, which is the strongest of the ten, refers to a specific sub-index in the third level of the BQI. The influence on final outcomes may be beneficial or harmful for the quality of the assessment depending on whether the assumption is weak or strong. A high influence is positive in the case of strong assumptions (lower average pedigree of other criteria).

The (im)plausibility scores showed a gap between the indexes and the 'reality' they seek to represent. What the beach indexes claim to do and what they actually deliver lack correspondence (as in Giampietro & Saltelli, 2014), at least for those assumptions carrying a higher conceptual load. Models and indexes can be wrong when scientific judgment happens to be external to what is at play (Allen, et al., 2017). Contrasting the narratives identified with both the results for analyst objectivity and the (dis)agreement between peers highlighted the role of the scientific background and interests in formulating the indexes.

The analysis showed a prioritization of the narratives related to sun, sea and sand recreation in all indexes, somehow still reproducing traditional approaches (James, 2000; Lozoya, et al., 2014). If other narratives, such as environmental protection were included in a balanced way, different goals and attributes could have been added in the form of dimensions and sub-indexes. In fact, the dimensions of beach SES not directly related to narratives for the recreational activity development, shared a need for the inclusion of more sub-indexes to better attend their objectives (such as in assumptions V and VII) and to update the existing ones (e.g. assumption VIII).

Advising for other beach management objectives rather than recreation (and combining them in a management strategy of a particular beach) requires further developments, though some authors have already advanced in this matter. McLachlan, et al. (2013) suggest the suitability of some beaches for displaying a mixed used (conservation and recreation) and Dadon (2018) suggests that successful beach management may deploy different objectives resulting from diverse intensities of three change drivers: the demand for quality services, public use and enjoyment, and the environmental sustainability.

The inclusion of new levels of complexity through the objectives of analysis can, if done properly, be a solution for existing problems (Allen, et al., 2017). The very first step for (re) building indexes should be to include the plurality of narratives and external references, setting out the different beach dimensions, elements and specificities (Mayumi & Giampietro, 2006; Garnåsjordet, et al., 2012) comprising this complex system. However, without the required reflexive processes of evaluation, we may not seek synthesis and harmonization (Podger, et al., 2016), nor properly account for all existing narratives. We should, thus, accept different values, interests and positions for a particular framework of data and sub-indexes, which would support tackling the relevant assumptions.

The average score for choice space demonstrated that, although small, there is room for indexes' updates that are capable of delivering more realistic approximations to complexity in the future. Alternatives to assumptions (re) emphasized the possibilities of including other narratives in the form of sub-indexes besides those focusing on recreational activities, and of including sub-indexes that are better suited to local specificities. In this regard, FGs participants suggested replacing some of the BQI-indexes with more realistic ones, that are more relevant to the Catalan case (e.g. assumptions VIII and IX) in spite of the uncertainties that these changes would imply, which highlighted the academic trend towards idealization above pragmatism (Arnott, et al., 2016). Complementarily, observing that the lowest average weakness scores were found for the criterion of influence of resource limitations, we inferred that the further improvement of better suited sub-indexes would not necessarily depend on more resources.

As already mentioned in Methods (section 3), the identification and assessment of assumptions is not an objective process (Kloprogge, et al., 2011), but doing so by including the proper participation of suitable stakeholders may help improve the management of uncertainties (Mayumi & Giampietro, 2006). The constant exchange between beach stakeholders and the attempt at identifying and reporting the main flaws of beach indexes should be promoted (Martínez & Dopheide, 2014). Development of the indexes based on an opening up of science, with greater public scrutiny and focus on precaution, could lead to more democratic, legitimized and creative results (Bremer & Glavovic, 2013a). We, therefore, recommend more in-depth NUSAP analysis for each of all indexes approached in this study. Also, an extension of the NUSAP analysis to indexes tackling other coastal areas and issues (e.g. vulnerability indexes) may be appreciated. This would build capacity on the process of knowledge assessment, generate inclusive dynamics and improve the discussion around uncertainties in coastal management.

5. CONCLUSIONS

The analysis carried out indicated that the assumptions are slightly robust, though attention should be especially paid to the criteria of influence on global outcomes, (im)plausibility and choice space. The highest scores (weakest) corresponded to the "all indexes' assumptions", which deployed an abstract nature (lower correspondence with particular objectives) and higher conceptual loads. For instance, the weakest assumption (number IV) is conceptual loaded by the choice for commensurability analysis, which leads to comparisons of different non-equivalent representations of the beach SES in all indexes, at least in their higher levels of hierarchy, and without a proper process of reporting.

The studied indexes addressed the complexity of recreational beaches in a limited way. Their assessments are biased, and do not completely account for alternative types of recreation and processes (ecological, economic and morphodynamics) important for their sustainability. In most cases, the way in which the results of the indexes are deployed do not reflect non-equivalent representations of the beach system, even when the focus on the recreational activity dimension was partially balanced by the inclusion of other dimensions. They also report the embedded uncertainties in an insufficient way. As regards the BQI assumptions, their higher contextualization and correspondence to more concrete objectives led to lower average pedigree scores (more robustness), although the analysis reflected the predominance of the narratives of economic growth and sustainable development, also setting a focus on recreation. Other narratives suggested the need for new or adapted sub-indexes and dimensions.

A difficulty was observed upon putting into practice the complex systems discourse when structuring all indexes. This was especially denounced by the average score of (im)plausibility for all assumptions and by a tendency to rely on decontextualized scientific data. Specificities regarding particular narratives, processes, and manifestations of complexity (e.g. epistemological and ontological diversity) need to be recognized and taken into account by the science-policy interface, whenever possible. For example, irreducible uncertainty means that even if ecology and natural heritage sub-indexes present high values of conservation, negative interactions may be happening, and might be a direct threat to certain species due to changes in a non-observed variable.

The identified areas for improvement in all indexes reinforced the potential of the PNS approach for supporting the knowledge quality assessment. The observation of different narratives made a more holistic understanding of beach SES conceivable. The present analysis was especially useful for finding and evaluating conceptual-loaded assumptions embedded in all indexes and for reiterating that the influence of case dependency on the definition of concrete objectives (seen in the BQI assumptions) may support more robust assessments.

Finally, it is important to note that the call to open up and pluralize science discussed in this study does not seek to deny the specialized competence of scientists, but rather to position them as one further element in the framework of possible beach epistemologies.

ACKNOWLEDGEMENTS

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2.2| A DOUBLE-LOOP PROCESS FOR BEACH QUALITY INDEX CONSTRUCTION: APPROACHING THE COMPLEXITY OF THE CATALAN COAST

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Research article

A double-loop process for beach quality index construction: Approaching the complexity of the Catalan coast

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Highlights

- A double-loop (DL) process of learning is presented to renew beach management tools.
- The embedded expanded peer assessment potentially boosts pertinence and usefulness.
- A double-looped beach quality index (DL-BQI) included the Catalan coast narratives.
- Pre-analytical choices were highlighted and focus on recreation was better balanced.

ABSTRACT

Sets of coastal management indicators have been used to summarize the main social, economic, environmental and political assets/processes of socio-ecological systems (SES). Their development and further assessment have, usually, been ruled by a process of four sequential steps (Selection/definition of indicators, Production, Assessment and Information for policy actions), in which feedback is limited to certain subjects and attributes. Quality checks regarding the information made available are rarely seen, somewhat disregarding the adaptive complex character of SES. In this study, we present the double-loop (DL) process of learning, aiming at improving the epistemological (usefulness) and pragmatic (pertinence) quality of knowledge. In practice, an expanded peer assessment has led to the adjustment of a previous beach management tool: The Beach Quality Index (hereinafter, the single-looped BQI), through the (re)selection, (re)definition and (re)production of indicators. By means of one multi-stakeholder meeting, five focus groups and interviews, four relevant narratives of the Catalan coast were identified. These narratives enabled the shaping of a wider perception of the observed system - the Catalan beaches - which highlighted the lack of integration in beach management processes. In order to respond to the aforesaid lack of integration and other shortcomings, by adding or updating the single-looped BQI indicators, a new formal system and the choices made were formulated and highlighted. This new set of indicators is here called the double-looped BQI, in which, especially, the previous preponderance of recreational activity was counterbalanced. Though further developments would still be necessary and *in situ* applications would help to check the feasibility of the logic applied, we recommend its inclusion in the beach quality research field to couple better with coastal management recommendations regarding governance and complexity.

Keywords: Sustainable indicators, Beach indexes, Double-loop process, Expanded peer assessment, Quality of knowledge, Science-policy interface.

1. INTRODUCTION

The integrated management and governance of socio-ecological systems (SES) in recent decades has been significantly supported by a widespread application of sets of indicators (hereinafter, index or a set of sub-indexes) (SbIs). The capacity of the SbIs to synthetize the complexity of the embedded main social, economic, environmental and political processes (OECD, 2008)—conceptualized as a formal representation of SES—particularly empowers them for evaluating and measuring trends. However, the formal representation of an SES is intuitively preceded by the shaping of the observed system under examination, which lies in a non-objective observation process of information acquisition. Here, the selection of the observer(s)' narrative(s) and subsequent pre-analytical choices (e.g., in a study of beaches, if the narrative considered corresponds exclusively to a conservation biologist, the main observations are possibly the existing biological communities and related processes) will ground the required encoding[9] and

[9] The procedure(s) of converting information into a coded form (Oxford-Dictionaries, 2018).

decoding[10] procedures. Respectively, representations of SES are, thus, formalized through a chosen set of attributes, variables and numerical values symbolizing the prioritized elements (what to observe, e.g., biological communities) and a chosen method of analysis (how to observe, e.g., the measurement of the state of these biological communities) (Rosen in Giampietro, et al., 2006).

In practice, the creation of the formal SbIs to measure sustainability of beach SES (e.g. (Ariza, et al., 2010; Botero, et al., 2015)) has followed a particular sequential chain (Figure 9): The single-loop (SL) process of learning (Garnåsjordet, et al., 2012) by which knowledge is incorporated through existing ways of conceiving an issue (Siebenhüner, 2002). All steps of this chain (in Figure 9, from 1 to 4) and the feedbacks on the outcomes of sub-indexes (down arrow) have usually been restricted for the majority of coastal stakeholders, limiting the narratives involved particularly to academic experts, except for the specific inclusions of beach users' preferences (Peña-Alonso, et al., 2018). In light of this, beach SbIs have prioritized recreation over other beach functions, such as the natural (Bombana & Ariza, 2018).

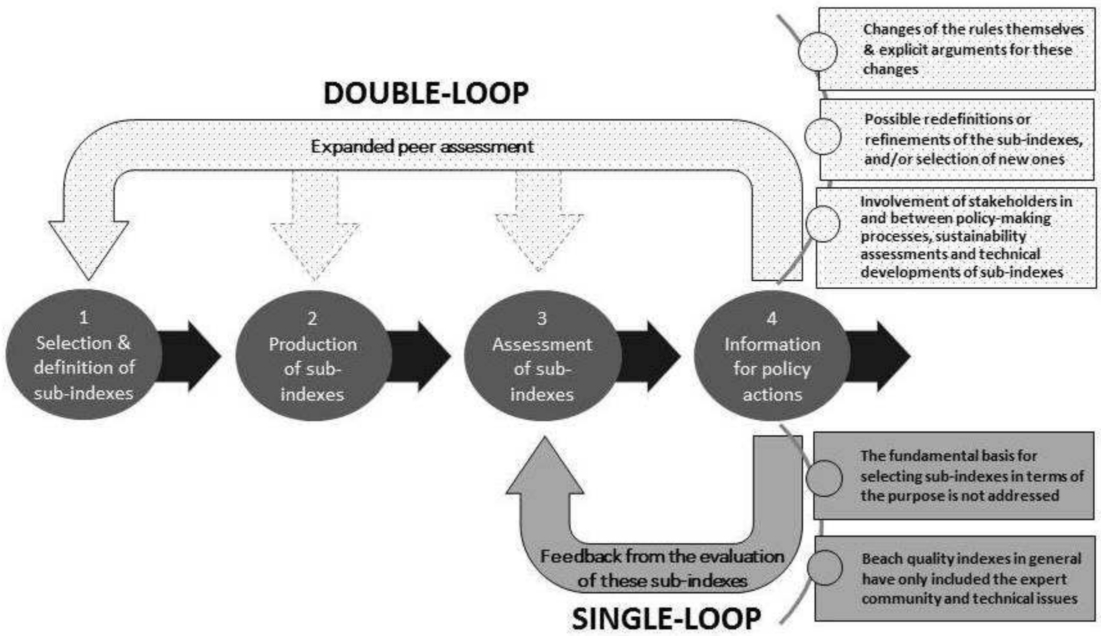

Figure 9. The standard pathway for the production of an index, i.e. a set composed by sub-indexes (or indicators). The down arrow corresponds to the integration of a single-loop process of learning in such pathway, while the upper arrow refers to the integration of a double-loop learning. Adapted from (Garnåsjordet, et al., 2012).

Kovacic and Giampietro (2015) called for an analysis of how indexes are formulated, which they describe as reflexivity on how values are arranged in the science-policy interface deliberating on complex systems. Due to the embedded uncertainty of these systems, quality should refer to epistemological and pragmatic plurality that enrich, respectively, the pertinence and usefulness of these assessments (Kovacic, 2015).

[10] The procedure(s) of converting a coded message into intelligible language, or of analyzing and interpreting (a communication or image) (Oxford-Dictionaries, 2018).

From this, the variety of non-equivalent representations and perceptions of a system (Mayumi & Giampietro, 2006) and the arguments behind the corresponding choices (Garnåsjordet, et al., 2012)—i.e., narratives—are recognized and included, and are linked to the legitimation of a credible science for policy (Dankel, et al., 2012), to the effective formulation and accomplishment of goals (Dahl, 2012; Martin, 2015), and to ethics (Reed, 2008). However, improvements in pertinence might be reached only by a direct association between the framing of problems and the representation of the system (in the encoding process), whilst usefulness depends on the correspondence between the outcomes of such representation and the defined objectives of analysis (in the decoding process) (Giampietro, et al., 2006; Kovacic, 2015).

To advance in pertinence and usefulness, a double-loop (DL) process of learning might constitute an alternative that enables the reevaluation of an operational scheme of values, practices and goals (Siebenhüner, 2002). In this work, we explore the progression from a SL to a DL logic throughout an expanded peer assessment (EPA) (up arrow in Figure 9) as the practice in which groups of lay people, the private sector, political representatives and the scientific community, with their non-equivalent narratives and values, are integrated and involved in the production and assessment of decisions affecting common problems (Van der Sluijs, 2017). This would therefore allow for feedback that is more plural to be included (from Step 1 onward), widening the procedures for observation, encoding and decoding in the assessment of beach systems, and consequently enriching the quality of knowledge available.

The Beach Quality Index (BQI) (Ariza, et al., 2010), built and applied in Catalonia, is one of the first attempts to assess beach systems multidimensionally (Williams & Micallef, 2009). Nonetheless, as with all the other beach indexes developed by a SL process, the quality of the knowledge made available by the BQI is still largely to be tested, especially regarding the enclosed pre-analytical choices, in spite of the recent analysis of its assumptions (Bombana & Ariza, 2018). Hence, the main objective of this work is to improve the pertinence and usefulness of this tool (hereafter, the Single-Looped BQI (SL-BQI)) by co-defining with stakeholders the perception of the observed system—Catalan beaches—considering its main problems, narratives and dimensions. Subsequently, we then focus on (re)building a representation of the observed system—the formal system—highlighting the choices made. We present this formal enhanced system, terming it the Double-Looped BQI (DL-BQI).

2. BACKGROUND

SbIs for the sustainable management of coasts began to be widespread after the Rio Earth Summit in 1992 (Dahl, 2012). Some were specifically designed to assess beach systems (BS) and, most of them responding to the need to classify beaches according to their recreational potential, were developed as rating schemes (e.g. Leatherman, 1997; Morgan, 1999), providing limited qualitative assessments of sustainability (Williams & Micallef, 2009). Since then, more evolved and inclusive indexes able to account for and quantify beach processes have been developed, such as Ariza, et al., (2010); Botero, et al., (2015); Lucrezi, et al. (2016); Todd & Bowa (2016) and Semeoshenkova, et al. (2017). All of them, however, the old and the new, have been elaborated by a limited number of coastal stakeholders who tried to embrace a high number of elements, pursuing techno-scientific and pro-tourism market narratives (Williams & Micallef, 2009; Peña-Alonso, et al., 2018). Pre-analytical decisions for most developed shores complied with the exclusion of some narratives, for example, when we assume that the greater the number of beach services and facilities, the greater the results of the beach assessment will be, we are indirectly depreciating other elements (e.g., the state of ecological communities) that could also, and sometimes instead, improve such an assessment. An expanded group of peers has never reviewed the development and use of SbIs. This is true even after the progressive implementation of Environmental Management Systems (EMS) for beach areas (Ariza, et al., 2007) and the proposal of Ecosystem-Based Management System for Beaches (Sardá, et al., 2015), which, based on adaptive cycles, would have had the potential to trigger DL processes in the aforementioned tools.

In a context of complexity, scientific assessments are challenged to prioritize the most relevant characteristics of a system (Kovacic, 2015). Since relevance is relative to those involved, a new paradigm for developing SbIs includes a dialogued understanding through the recognition of diverse narratives capable of explaining the observed system (Mayumi & Giampietro, 2006; Sorman & Giampietro, 2011; Podger, et al., 2016). Narratives are "histories" (i.e., semantic expressions) used, by one or more stakeholders, to elucidate about reality and desires and to put values in context (Shields, et al., 2002; Giampietro, et al., 2006). When placed in plenary, narrative(s) result in objective(s) which will depend on an external referent to set the relevant attributes, causal relations and the proxy variables used in quantification (Garnåsjordet, et al., 2012). This referent applies to the natural limitations of a system (e.g., the assessment of the state of dunes is constrained to the aerial zone of sandy beaches, since these coastal forms exclusively develop in this particular beach type and zone).

Sub-indexes developed through hybrid – merged top-down and bottom-up – methodologies (Reed, et al., 2005) have been increasingly developed in recent decades in diverse fields, including coastal and beach management. Across one or more steps of the development chain (Figure 9), different levels of public engagement between academic and non-academic stakeholders are, thus, seen[11] (e.g. (Botero, et al., 2015; Iribarnegaray, et al., 2015; Ferreira, et al., 2018)). Nevertheless, few are anchored in a complete DL process (Reed, et al., 2006), which would account for quality checks regarding the rigorousness of the methods applied (Kovacic, 2015) and for adaptive management processes according to the evolution of shared values (Plumecocq, 2014). Expressly, Giampietro, et al. (2006) claim that the pre-analytical choices about which perceptions of the observed system are relevant and how these are represented and formalized through a set of observable attributes in the scientific model – as a SbIs can be - should be approached from the beginning of the scientific inquiry and, once

[11] The nature of public engagement can be of three types: 1. "Communication", i.e., passive reception of information; 2. "Consultation", and 3. "Participation" (Rowe & Frewer, 2000). In these last two, participants and research developers exchange information by means of a dialogue or negotiation process.

applied, be recaptured in an endless loop for the progress of knowledge. This is the main contribution of the DL process, particularly through the EPA.

Bombana and Ariza (2018), in a recent study, called for an expanded review of the SL-BQI. This index, in its original formulation, was structured in four hierarchical levels: 1) The overall tool, 2) Three beach functions, 3) Thirteen sub-indexes (each one pertaining to one of the beach functions), and 4) The measurement attributes and corresponding variables. The authors scored beach functions and global beach quality through normalization, aggregation and weighting practices (0 - worst situation to 1 - best situation).

The EPA would make it possible to tackle the observed shortcomings: the somewhat arbitrary structure existing, the lack of democratic legitimacy, practical difficulties on measuring some variables, trust in precision by deploying single numbers and, consequently, omission of ignorance (Landerretche, et al., 2017). A DL process applied to the SL-BQI could possibly address the mentioned weaknesses in an enhanced tool – the DL-BQI - through the contextualization of changes and the arguments behind them, and the highlighting of the new/updated sub-indexes, data, measurement schemes and embedded uncertainties, accordingly.

3. METHODS: PLACING THE SL-BQI IN THE GOVERNANCE PROCESS THROUGH A DOUBLE-LOOP LEARNING PROCESS

The standard expert-conducted sequential process in Figure 9 was followed by Ariza, et al. (2010) for the formalization of the SL-BQI (Spheres 1 to 4) and corresponding assessment in six Catalan beaches (down arrow). Alternatively, in this research, we intended to develop a DL-BQI by approaching the potentiality of the DL learning model (Spheres 1 to 4 plus up arrow of Figure 9) in stressing the “story behind the data”. In this primary approximation, we focused on the selection, definition and production of the DL-BQI sub-indexes (Steps 1 and 2 of Figure 9) from the EPA, of which fuller details are given in Figure 10 and which is described more completely in sections 3.1. and 3.2.

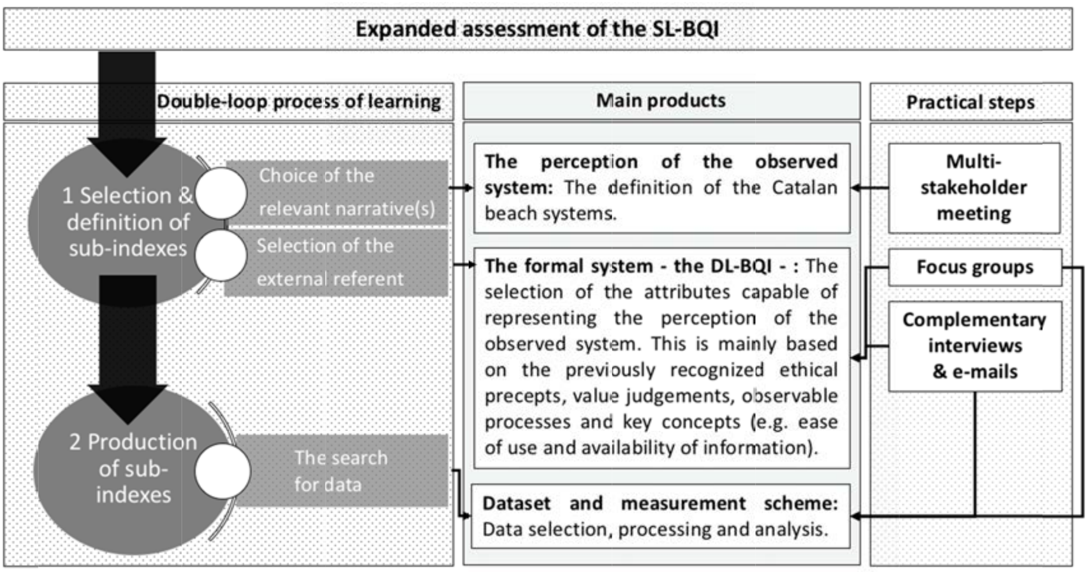

Figure 10. The methodological scheme applied for the selection, definition and production of the DL-BQI. Source: Own elaboration based on Garnåsjordet, et al. (2012).

3.1. The pre-(re)construction of the DL-BQI: Defining the perception of the observed system

In this section, we identified, analyzed and combined the narratives explaining the Catalan beaches.

3.1.1. Multi-stakeholder meeting (MS-meeting)

First, we defined and elaborated the current main narratives of the Catalan coast (Figure 11) through a multi-stakeholder whole day meeting (Molina, 2016), held in Barcelona on April 1st 2016. It was attended by fifty-seven stakeholders from the three levels of government (State, autonomous community (AC) and municipalities), private consulting firms, academic experts (from biophysics-ecologists to social sciences, such as law schools, and polytechnic schools) and organized civil society (such as fisheries and nautical sports federations, and citizen platforms representing environmental resources, naturists and handicapped people) (Molina, 2016). We adapted and applied the Participatory Planning and Associate Management methodology (Poggiese, 1993) across which the main conditionings, trends, positive processes and key stakeholders were co-identified. This process allowed an approximation to the perception of the observed system, in which the main characteristics, problems and challenges could be highlighted, leading to the stakeholder agreement of the most important shortcoming for coastal management: *the lack of a long-term and integrated beach model for the sustainable management of the Catalan coast*.

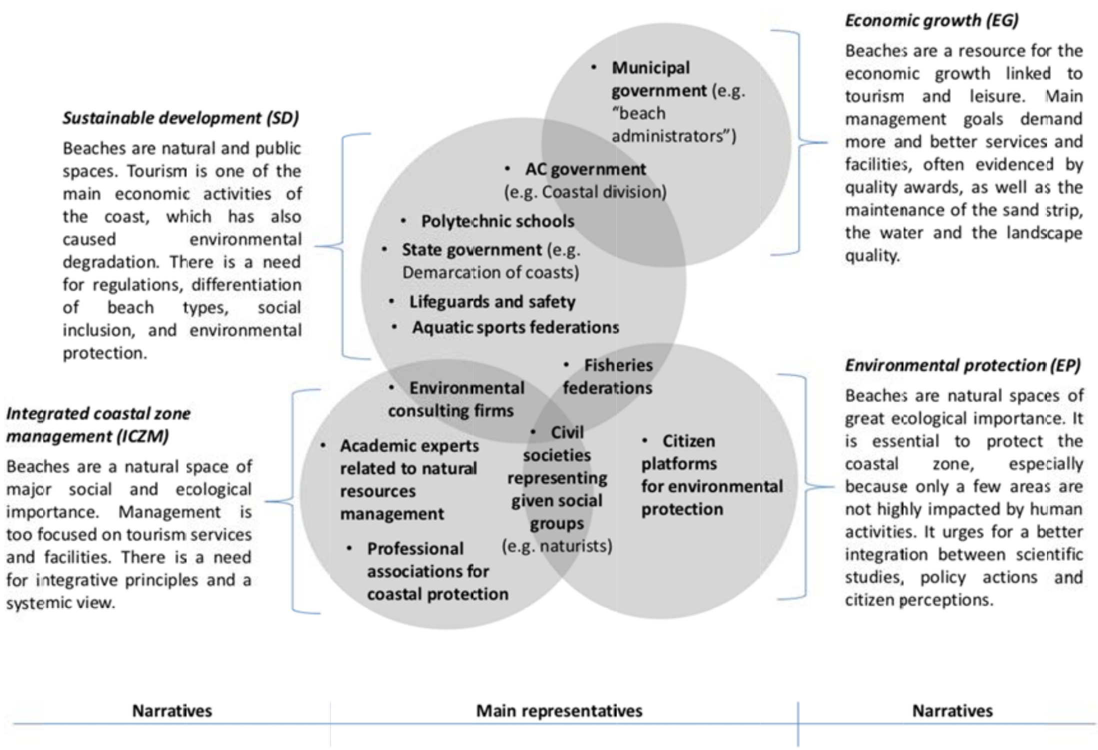

Figure 11. Identification and brief explanation of the main narratives used to explain the Catalan beach systems. The figure also shows how stakeholders are generally positioned regarding the narratives. Adapted from Molina (2016).

The assembled information was used to understand the Catalan beach systems, especially defining their composing dimensions and boundaries (Table 9). These formed the organization scheme of the formal system, i.e., for each dimension identified, a set of specific objectives, attributes and variables was assigned (Munda, 2005). It is noteworthy that most of the stakeholders often used one or more narratives during the discussion (Molina, 2016) to provide insights on the beach socio-ecological systems of Catalonia, which brought out the non-exclusivity of a single one. The whole assemblage of narratives should, thus, be approached in further steps.

Table 9. Dimensions composing the perception of the observed beach system in Catalonia.

Dimension	Definition
1 Recreational activity	The set of recreational activities developed within the (emerged and submerged) beach area and surroundings, as well as beach users' responses and preferences.
2 Morpho-dynamics	The interactions between coastal floor, sediments and hydrodynamic agents (e.g. waves and coastal rivers), and also the anthropic activities affecting such interactions (e.g. beach nourishment).
3 Ecology & Natural heritage	The biotic communities, non-biotic assets and interactions capable of forming and running the corresponding ecological system and natural heritage.
4 Beach economics	The monetary transferences resulting from the use of beach resources and activities, and further outcomes.
5 Governance & Management	The decisions, tools and dynamics that put in practice coastal management plans and programs. These should occur besides the government sphere, through the inclusion of other institutions and collectives.

With the goal of informing regional policy, we selected a scale of analysis capable of approaching all types of beaches existing in Catalonia. This scale was combined with further local scales when focusing on the different sections of the whole system, e.g., because of the interactions flowing inside these cells, the scale of water bodies (wider than a beach) is used by the sub-index, with a view to approximating the ecological and chemical quality of water at beaches in a general sense, although it cannot capture specific affectations in space and time. Additionally, the sub-index used to assess the current conditions of dune systems will only be applicable to those beaches with a potential to host dunes (Garcia-Lozano & Pintó, 2018).

3.2. The (re)construction of the formal system: The DL-BQI and its measurement scheme

A formal system – such as the DL-BQI – is conceptualized as the set of finite relevant qualities and linkages used to represent the chosen perception of the observed system (Mayumi & Giampietro, 2006). After shaping a wider perception of the observed system, through the following procedures (focus groups and complementary interviews and e-mails), we checked whether the previous formal system – the SL-BQI – corresponded to it. The identified non-correspondences were, thus, discussed and some of them addressed in the DL-BQI. Here, we aimed to present sub-indexes capable of expressing the different narratives in a way that did not subsume any of them, but reflected the tradeoffs of the different policy options.

3.2.1. Focus groups (FGs) and complementary interviews and e-mails

We planned and carried out five FGs, one for each of the five beach dimensions identified (Table 10). In total, twenty-four different participants attended, but some participated in more than one FG. The selection of the attendees was in accordance with the proximity of their competences to the dimension (Table 9) targeted by the FG. In practice, we presented, analyzed and subsequently discussed the SL-BQI sub-indexes. For each sub-index, the participants were asked to check its consistency with the reality of the Catalan coast, the need for changes (e.g., to adapt the sub-indexes according to the levels of urbanization in the beach surroundings) and the possible limitations of resources to implement these. The potential inclusion of new sub-indexes was also discussed with the participants. Consequently, we were able to (re)define *which elements* of the beaches should be observed and *how* these elements should be observed. We were also able to question the participants about the data available and the focus of *in-situ* measurement and suitable scales, i.e., both the external referent and/or search for data (Figure 10).

Table 10. Structure of the FGs: Sub-indexes and narratives approached, and the number and profile of the participants.

FG	Discussed SL-BQI sub-indexes	Participants		Main narratives approached
		Nº	Main profiles	
Recreational activity	Microbiological water quality, Beach crowding, Environmental quality, Services and facilities, Activities, Access and parking, Comfort quality and Beach Safety	6	**Academic peers:** 1 Social perception expert, 2 Coastal tourism and leisure experts, 1 Integrated beach management expert **Local government:** 1 Decision maker on environmental affairs, 1 Specialist in reduced mobility	Economic growth
Ecology & Natural heritage	Quality of surrounding area, Natural conditions and Water-sand pollution	5	**Academic peers:** 1 Integrated beach management expert, 1 Coastal geography expert **Regional administration:** 1 Specialist in Landscape planning **Consulting company:** 1 Coastal information maker and user **Organized civil society:** 1 Environmental protection activist	Environ-mental protection, Integrated coastal zone managemen t
Morpho-dynamics	Physical Quality and Protection	6	**Academic peers:** 2 Coastal geology experts, 1 Coastal engineering expert **State administration:** 2 Specialists in Coastal engineering **Consulting company:** 1 Specialist in beach restoration	Economic growth, Sustainable developmen t
Economics	Economic valuation methods available	7	**Academic peers:** 1 Economic geography expert, 1 Coastal geography expert, 1 Integrated beach management expert, 1 Sustainability expert, 1 Tourism economy expert, 1 Coastal economy expert, 1 Information systems expert	Economic growth, sustainable developmen t and Integrated coastal zone managemen t

[Continuation of Table 10]. Structure of the FGs: Sub-indexes and narratives approached, and the number and profile of the participants.

FG	Discussed SL-BQI sub-indexes	Participants		Main narratives approached
		Nº	Main profiles	
Governance & Management	Do not correspond	7	**Academic peers:** 1 Governance expert, 1 Coastal geography expert, 1 Sustainability expert **Regional administration:** 1 Specialist in Landscape planning, 1 Specialist in Land use planning **Local government:** 1 Decision maker on environmental affairs **Organized civil society:** 1 Environmental protection activist	All narratives

3.2.2. Transcription, coding and organization of what we should observe and how

We identified the relevant information due to the ethical precepts, value judgements and observable processes explicated by the participants. This information was, thus, detached and organized, whether according to its correspondence to the SL-BQI sub-indexes, or as inserted elements potentially leading to the creation of new sub-indexes. We also stuck to the idea that, in a context of "multiple stories" told and confrontation of scientific information, the principle of an ease of use[12] (Reed, et al., 2006) should be followed. Mainly, we avoided choosing too numerous sub-indexes that the production and assessment of their variables might evolve into high resource-demanding activities, but not too few that relevant relations and processes happening in and across dimensions would not be observed (Bossel, 2001). During this process, whenever a gap of information was detected in the FGs' outcomes, we proceeded to identify, contact and interview the experts who could provide knowledge on the matter. In total, seven experts were contacted through formal or informal interviews after the FGs.

Finally, we organized the results into four descending levels: 1) The overall DL-BQI deploying the overarching strategic objective; 2) A set of sub-indexes per dimension, each linked to a particular fundamental objective; 3) Specific sub-indexes each responding to a partial objective; and 4) The attributes that compose a sub-index, i.e., relevant properties of an entity or process (Shields, et al., 2002).

4. RESULTS AND DISCUSSION

4.1. The perception of the observed system

The selection and definition of the sub-indexes (First step in Figure 10), primarily, lay in constructing the perception of the Catalan beaches (summarized in Figure 12)—our observed system (Giampietro, et al., 2006)—which should be composed of, at least,

[12] In addition to aiming at straightforward measurement schemes, we expanded this criterion towards other SI objectives, such as making use of available data; having social appeal and resonance; being developed by end-users, etc. (Reed, et al., 2006).

those dimensions highlighted in Table 9. To this end, Governance & Management were taken as an umbrella dimension (larger circle in Figure 12) for the other four (four inner circles in Figure 12): Beach economics, Recreational activity, Ecology & Natural heritage, and Morphodynamics; reflecting a concern for the way that knowledge is (co)built, transferred and made available to support and apply decisions (Bremer & Glavovic, 2013b). From the choice of this skeleton, we attempted to attain the identified narratives (Figure 11) according to their capacity for explaining beach dimensions (e.g., the EP narrative mainly explained the processes and assets of the Ecology & Natural heritage). The wider set of narratives dissented from the SL-BQI, in which the EG narrative predominated, followed by the SD narrative (Bombana & Ariza, 2018). Furthermore, the definitions of the Catalan beaches were assembled in the upper-left corner, highlighting their complexity, dynamism and condition as both diminishing and public socio-natural spaces. Finally, the main problem facing our coastal territory was co-defined as follows: *The lack of a long-term and integrated beach model for the sustainable management of the Catalan coast,* in degrees explained by minor contemporary problems (right-hand side).

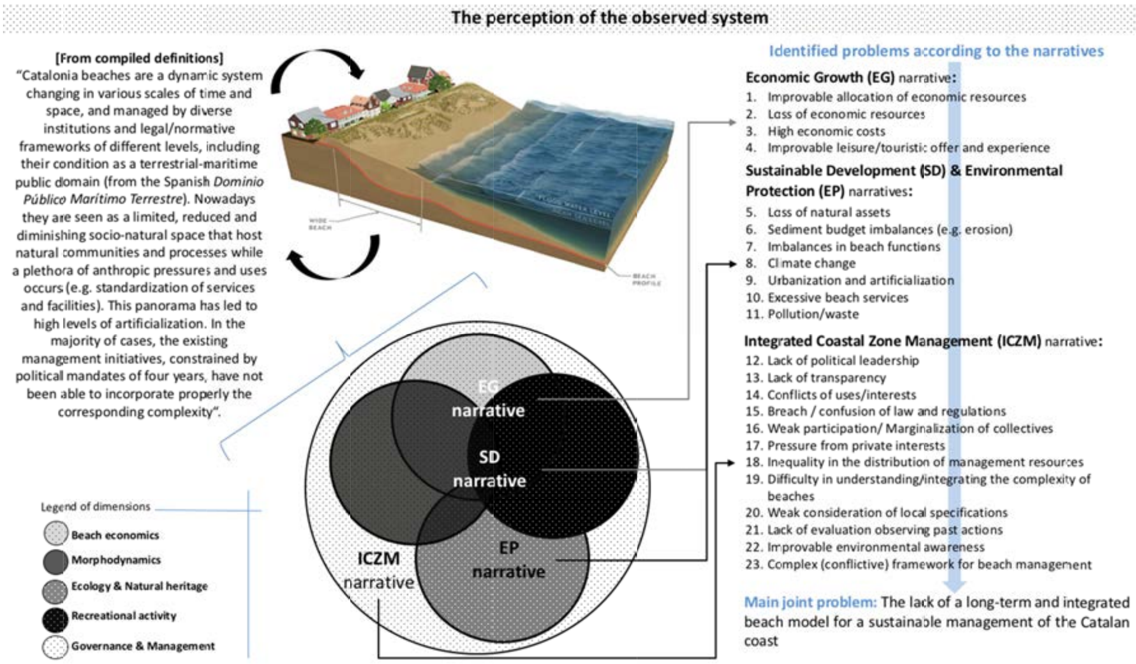

Figure 12. The perception of the observed system: The way in which the identified narratives distribute across and explain the beach system of the Catalan coast. Source: Own elaboration.

The convergence in perception among actors about the lack of an integrated model is assumed in this paper as proof of the convenience of establishing a DL process and its subsequent EPA in which deliberation among different stakeholders might be triggered. The ICZM narrative as an assembler of the other narratives could address such a shortcoming and, particularly, corresponds to the processes happening in the wider Governance & Management dimension. It is noteworthy, though, that the DL-BQI should be considered as a tool intended to aid governance and management, instead of being a governance process in itself. To cite an instance, the aforesaid deliberation would possibly improve political engagement, but not expressly interfere with the level of political will and leadership.

4.2. The representation of the observed system: The Double-Looped Beach Quality Index (DL-BQI)

We continued with the selection and definition of sub-indexes by approaching the selection of the external referent and shaping the formal system, finally producing the sub-indexes (Steps in Figure 10): The formal DL-BQI (Figure 13). The cornerstone structuring the formal system, i.e., the overarching objective of transparently capturing the state of different beach assets in order to potentiate policy actions and aid for sustainability of the Catalan coast, corresponds to the dimension of Governance & Management (larger circle). For each of the other dimensions, represented by the inner circles, we highlighted a fundamental objective at which a given set of sub-indexes should aim (the greater the number, the larger the corresponding circle area). The sub-indexes were, thereupon, (re)organized according to the dimension they related to the most, instead of distributing them into beach functions like in the SL-BQI, because the conception of function usually limits the analysis to a single process of the BS (MEA Board, 2005).

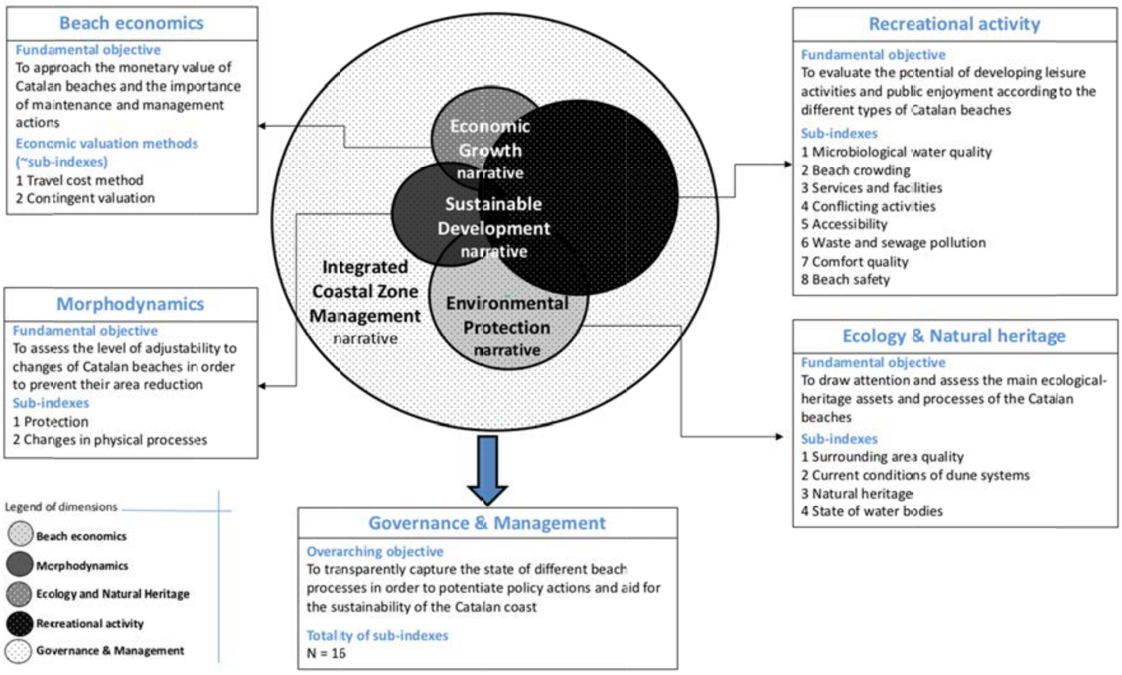

Figure 13. The DL-BQI making its overarching objective operational inside the Governance & Management dimension. The other dimensions were assigned a fundamental objective and a set of sub-indexes. Source: Own elaboration.

The choices made to represent the observed system in practice - the DL-BQI - are detailed in Table 11: the selected sub-indexes, the updates in relation to the SL-BQI, their partial objectives, the observation scheme, the descriptive domains, and the attributes/variables and scales of analysis. The updates described in column 2 refer to changes in the previously SL-BQI sub-indexes (e.g., for services and facilities, the convenience of the presence of a public telephone has been substituted by the existence of a mobile signal or Wi-Fi), or to newly added sub-indexes (e.g., the natural heritage sub-index that draws attention to the conservation interest of beach assets). In Appendix B, we present the DL-BQI structure: the sub-indexes, attributes and corresponding variables. In order to address incommensurability (Giampietro &

Saltelli, 2014; Bombana & Ariza, 2018), we declined the use of weighting and aggregation procedures between dimensions (2nd level) that would allow a global score to be obtained for the DL-BQI (1st level). Outcomes in these levels, therefore, should be represented differently, e.g., by graphical tools, such as radar diagrams (Gomero & Giampietro, 2005). Inside the structure of sub-indexes, though, normalization and aggregation methods were applied to make data comparable and enable a final score (between 0 and 1), i.e., scores were assigned to the attributes and variables (3rd and 4th levels).

In the DL-BQI, first we tackled the EG narrative, mainly the improvable leisure/tourist offer and experience and loss of economic resources by, respectively, enhancing recreational activity sub-indexes (e.g., accessibility, comfort, and services and facilities) and highlighting such a loss of resources (e.g., the current conditions of dune systems sub-index). The preponderance of this narrative in the SL-BQI (Bombana & Ariza, 2018) – mostly linked to " 'hazards-playground' view" of beaches (James, 2000) - showed that new corresponding sub-indexes in the DL-BQI would not be required in the dimensions of Recreational activity and Morphodynamics, their updates being satisfactory. However, by appreciating other narratives, the addition of sub-indexes and attributes might become imperative if we are to prevent the perpetuation of the actual management, co-defined as non-integrated, and to enhance usefulness for policy-making (Kovacic & Giampietro, 2015). As in the present case, the natural heritage sub-index (related to the EP narrative) was added to assess the Catalan beaches' natural heritage, for the first time, approaching the interest in conservation of these SES for the entire territorial scale studied. Also, we withdrew the HP method which focuses on the indirect impact of beach location in the real estate market and presents difficulties when applied to beaches with low samples of hotels and/or houses in the surroundings (e.g., usually, natural beaches). Instead, the Contingent Valuation was included with the intention of approaching the monetary importance of different beach management actions for beach users, not only focused on tourism/leisure, e.g., environmental conservation actions. We assumed that its outcomes could put light on how to allocate resources (EG problem linked to ICZM) and not just estimate the indirect monetary value of beaches (as in the HP method).

Following that, the SD narrative which was, earlier in the SL-BQI, partially addressed by the environmental requirements for the development of recreational activities (e.g., the microbiological water quality) and natural function sub-indexes, is now better considered and somewhat merged with the previously "inexistent" EP narrative. This EP poses the ecological value of beaches as central and the views and perceptions of citizenship as an important input, but the SL-BQI, especially, made use of commensurability to assess different assets of beaches with a special focus on recreational activity, above all without taking into account non-academic parts. Thus, though the SD and EP narratives may be differentiated according to their level of permissiveness of human activities, both called for the inclusion of natural beaches, for the improvement of natural asset/process monitoring, and for the consideration of local specificities.

4.2.1. Some of the examples regarding the changes mentioned are:

a) The **current conditions of dune systems sub-index** (from Pintó, et al., 2014) updates the former natural conditions sub-index (formed by the vegetation representation, dune surface and development of the habitat in terms of state of the dune belt) and now includes the last local scientific advancements (EP narrative) which aimed at providing, compared to other instruments, a quick global view (ease of use concept) of the state of dune systems by looking at 13 variables of dune morphology, vegetation and human impact, e.g., dune type and area, beach raking and list of plants found in the dune system. It would support an enriched evaluation of the loss of these natural assets (EP/SD problem), but calls attention to the fact that only 30% of all Catalan coasts meet the conditions for dune belts to develop (Garcia-Lozano & Pintó, 2018). Particularly, it indicated that we should consider other sub-indexes, besides the one in question, if we aim at supporting a wider consideration of beaches' natural conditions (e.g., by adding the natural heritage sub-index);

a) To enhance **accessibility** and the corresponding **sub-index**, which relates both to the improvable leisure/tourist offer (EG problem) and to the democratic access that should be guaranteed to public spaces (SD narrative and DPMT condition), we updated the former SL-BQI access and parking sub-index to comply with the reverse traffic pyramid[13] by means of which the balance between accesses for disabled people, pedestrians, cyclists, public and private transportation would be enhanced, e.g., inclusion of the assessment of bike lanes in the case of urban and semi-urban beaches. Besides, we took the care to interconnect the expected accessibility with the urbanization level in the surroundings (consideration of local specificities, i.e., ICZM problem). In this way, for example, we withdrew the quality of asphalt assessment for all types of beaches which would bias the choice for private and public transportation at beaches at the same time as it would encourage the artificialization of all accesses through accessible car routes;

c) The **changes in physical processes sub-index** replaces the physical quality sub-index (composed by changes in the grain size, beach area and wave regime). Though both sub-indexes intended to identify the anthropic changes occurring at beaches (SD narrative related to the loss of economic resources), the newly added one supports such identification in a more direct and easier way (ease of use concept), i.e., check with the corresponding administration if there were engineering works carried out at the beach. Moreover, by looking at the works located on any beach of the Catalan coast indistinctively, it tackles the uncertainty related to the former changes in grain size attribute, which could be occurring due to natural dynamics, such as in those areas close to river mouths (local specificities, i.e., ICZM problem), thus, not being generally applicable.

[13] Priority is given, in descending order, to disabled people, pedestrians, cyclists, public and private transportation (Bicycle Innovation Lab, n.d.).

Table 11. The detailed DL-BQI: Updates, partial objectives, observation scheme, descriptive domain, attributes/variables and scales of analysis of the sub-indexes.

	Sub-index	Main updates in relation to the SL-BQI	Partial objective	Observation scheme	Descriptive domain	Attributes/variables	Scale of analysis	
							Time*	Space
Recreational activity*	Micro-biological water quality	Now fulfills the requirements of Directive 2006/7/EC: Bathing area quality	Detect organic pollution	Ensure public health maintenance in bathing areas	Micro-biology, Epidemiology	*Escherichia coli, Enterococcus intestinals*	Days	Sub-merged part of the beach
	Beach crowding	Inclusion of thresholds for natural beaches	Detect overuse	Overcrowding may negatively impact tourist activities	Human Geography	Beach crowding (m^2/user)	Hours-Days-Seasons	Aerial part of the beach
	Waste and sewage pollution	Inclusion of thresholds for natural beaches, redistribution of the importance given to each variable and consideration of pollution at the beach accesses	Monitor aesthetic and hygienic environ-mental quality of sand and water	User satisfaction depends on aesthetic perception	Environ-mental management	Water quality (color, transparency, solid human waste, plant waste, marine plant waste, foam, presence of jellyfish, tar, oil, odor), state of entrances, sand quality (beach user waste, human waste, plant waste, marine plant waste, tar, presence of jellyfish), presence of rainwater outfall, beach closure	Hours-Days	Entire beach and sea promenade (when present)
	Services and Facilities	Inclusion of thresholds for natural beaches and improvement of accessibility for handicapped people	Assessment of the quantity/ quality of services and facilities present at the beach	User satisfaction depends on the adequate (neither too much nor not enough) provision of services and facilities	Planning of public areas	Density of services and facilities, beach guarding, showers and footbaths, parasols and hammocks, garbage cans, facilities for children, bathing support areas, restaurants/bars and stalls, mobile or wi-fi signal, information, sanitary facilities, sports facilities	Seasons	Aerial part of the beach
	Conflictual activities	Consideration of more conflictual activities, plus thresholds for natural beaches	Detect conflictual activities	User satisfaction depends on the avoidance of certain activities in beach resting areas	Human Geography	Pets, fishing, sailing, peddlers, sports, loud music/noise and perception of robbery	Hours-Days	Entire beach

[Continuation of Table 11]. The detailed DL-BQI: Updates, partial objectives, observation scheme, descriptive domain, attributes/variables and scales of analysis of the sub-indexes.

	Sub-index	Main updates in relation to the SL-BQI	Partial objective	Observation scheme	Descriptive domain	Attributes/variables	Scale of analysis	
							Time*	Space
Recreational activity*	Accessibi-lity	Now prioritizes, in descending order, disabled people, pedestrians, cyclists, public and private transportation(BIL n.d.); and includes thresholds for natural beaches	Evaluate accessibility to the surroundings and to the beach itself in the frame of the accessibility pyramid (BIL n.d.) and by considering different levels of urbanization	A decent access to beaches for all types of users should be guaranteed	Planning of public areas	Signposting, parking, parking fee, distance of parking, distance of parking for disabled people, bicycle lane, bicycle parking, pavement, public transportation, public transportation disabled people, distance pedestrian entrances, footbridges	Seasons-Year	Terres-trial beach surroundings and acces-ses
	Comfort quality	Improves climatic comfort attributes (Morgan, et al., 2000) and differentiates slope for two types of beaches: abrupt and low/deltaic coasts	Monitor comfort of beach users	Comfort is the product of the geomorphological conditions, water temperature and climatic conditions of the beach	Human geography	Beach width, slope of dry area, slope of wet area, obstacles, step, abrasive material, presence of jellyfish, water temperature, % rainy days, % cloudy days, % of strong wind	Days-Months	Entire beach
	Beach safety	Substitutes the former attributes by the results of a working group[14] developed in Catalonia, in which it was suggested that we should differentiate high, medium and low risk beaches	Provide a measure of safety conditions	The users should be protected from eventual risky situations	Risk management	Human resources (supervisor, lifeguard, recreational boat), surveillance point, medical emergency and first aid, rescue boat, vehicles, signposting, communication, sea mark	Seasons	Entire beach
*	In this dimension, measurements are mainly constrained to sunny hours							

[14] Formed by the Catalan Federation of Rescue; Association of Catalan Aquatic Rescue Companies; Catalan Red Cross; Federation of Municipalities of Catalonia; Catalan Association of Municipalities; Barcelona Provincial Council; Catalan Water Agency; Catalan Police; General Directorate of Prevention, Extinction of Fires and Rescue; System of Medical Emergencies; and *General Directorate of Civil Protection*.

[Continuation of Table 11]. The detailed DL-BQI: Updates, partial objectives, observation scheme, descriptive domain, attributes/variables and scales of analysis of the sub-indexes.

	Sub-index	Updates in relation to the SL-BQI	Partial objective	Observation scheme	Descriptive domain	Attributes/Variables	Scale of analysis	
							Time*	**Space**
Ecology & Natural heritage	Quality of surround-ding area	Addition of natural beaches	Monitor increasingly degraded coastal landscape	The terrestrial and aquatic imperviousness of the territory should be avoided	Landscape management and conservation	Impervious surface, coastal defense works, water table, impervious land use in the viewshed	Years-Half decade	Beach surround-dings
	Current Conditions of Dune Systems	Substitution for the Current Conditions of Dune Systems (Pintó et al., 2014) (more in further discussion)	Assess quality of the dune systems in the wind-controlled upper part of the beach	Where there is a potential to host dune systems, a good state of these should be promoted if we aim at a long-term sustainability of sandy beaches	Coastal geomorphology and Ecology	Dune type, dune area, dune length, mean height of dunes, built environment, car parking/tracks, beach raking, density of erosion pathways, dune breaches, invasive species, fixed dunes, no. of plant species found in the dune system, potential no. of dune-restricted plant species	Years-Half decade	Beach-dune systems
	State of water bodies	Now includes the requirements of Directive 2000/60/EC: Ecological quality of waterbodies	Monitor and control the ecological and chemical state of waterbodies, these not just being seen as resources, but as a structural and functional part of the natural system	The ecological and chemical quality of water bodies indicates the level of contamination and degradation, and aids their protection	Aquatic ecology	IFAN Index, preferred substances, seagrass, phytoplankton, seaweeds, macroinvertebrates, priority substances	Years	Aquatic part of the beach

[Continuation of Table 11]. The detailed DL-BQI: Updates, partial objectives, observation scheme, descriptive domain, attributes/variables and scales of analysis of the sub-indexes.

	Sub-index	**Updates in relation to the SL-BQI**	**Partial objective**	**Observation scheme**	**Descriptive domain**	**Attributes/Variables**	**Scale of analysis**	
							Time*	**Space**
Ecology & Natural heritage	Natural heritage	New	Detect coastal assets valuable for conservation	Coastal habitats and heritage should be protected for long-term sustainability	Conservation biology and geology	Coastal habitats of interest for conservation (General distribution inside Europe, frequency inside the Catalan territory, form of territorial implementation, biodiversity, degree of maturity, degree of threat), marine heritage and geological interest (Tourist interest, didactic interest 1 (information level and basic education), didactic interest 2 (teaching at middle and upper levels), scientific interest)	Years - Decade	Entire beach and surround-dings (300m)
Morphodynamics	Protec-tion	Tackles the former method's uncertainties (e.g. the disregard for the height of the aerial part of beaches and the non-calibration of the *Sbeach* model, used to estimate its variables)	Assess the erosion hazard on beaches	The sustainability of beaches depends on maintaining their buffer potential against sea energy	Coastal Geomorpho-logy and Engineering	Number and magnitude of harmful events	Seasons-years	Immediate coastal infra-structure
	Changes in physical processe s	Tackles the former method's uncertainties (e.g. changes in grain size do not necessarily correspond to anthropic changes)	Monitor the effects of human activities on beach natural processes	Anthropic changes threaten the stability of coastal systems	Costal Geomorpho-logy and Engineering	Number and magnitude of engineering works	Half to entire decade	Littoral sedi-mentary cells

[Continuation of Table 11]. The detailed DL-BQI: Updates, partial objectives, observation scheme, descriptive domain, attributes/variables and scales of analysis of the sub-indexes.

	Sub-index	Updates in relation to the SL-BQI	Partial objective	Observation scheme	Descriptive domain	Attributes/Variables	Scale of analysis	
							Time*	Space
Economics	Travel cost method	Maintained (Ariza et al. 2012)	Assess the willingness to pay to visit a certain beach	Beach features have the potential to generate income, given that users are willing to invest time and financial resources to enjoy the beach	Environmental economics	Individuals' willingness to pay to visit the beach (individual expenditure (€)/day), Accumulated individuals' willingness to pay for this activity for the entire beach (total expenditure (€)/day)	Seasons	Entire beach
	Contin-gent valuation	Substitutes the Hedonic Prices (HP) method (Ariza et al. 2012)	Estimate the monetary value of beach assets in a hypothetical market	Beach users might indirectly pay to maintain/restore beach assets	Environ-mental economics	Percentage of taxes that beach users would assign to beach maintenance and management	Seasons	Entire beach

4.2.2. Wrapping up advances

Updates and/or additions were introduced in all sub-indexes, except for the maintenance of the Travel Cost Method, aiming at balancing all narratives by approaching the main interdisciplinary biases that, previously, created gaps in some areas while densifying others (Bossel, 2001). Good examples of these changes relate to the inclusion of specificities of the Catalan coast (mainly, ICZM problem), a stronger inclusion of citizenship and scientific advancements in the assessment (EP narrative), the appliance of the concept of ease of use (Reed, et al., 2006) and further outcomes that would support adapted regulations (SD). In Figure 14, such counterbalance is illustrated by distributing the corresponding sub-indexes of the SL-BQI (black dots) and DL-BQI (blue dots) according to the narratives (big circles) to which they were/are most linked. We should recall that stakeholders often used one or more narratives to explain processes of Catalan beach systems (Molina, 2016), later transposed into sub-indexes, but the full application of these narratives altogether may be impossible given the non-equivalencies between certain discourses (e.g., EP and EG which, respectively, see beaches as exclusively natural spaces or ideal for the development of economic activities), which explains the lack of sub-indexes in the convergent center.

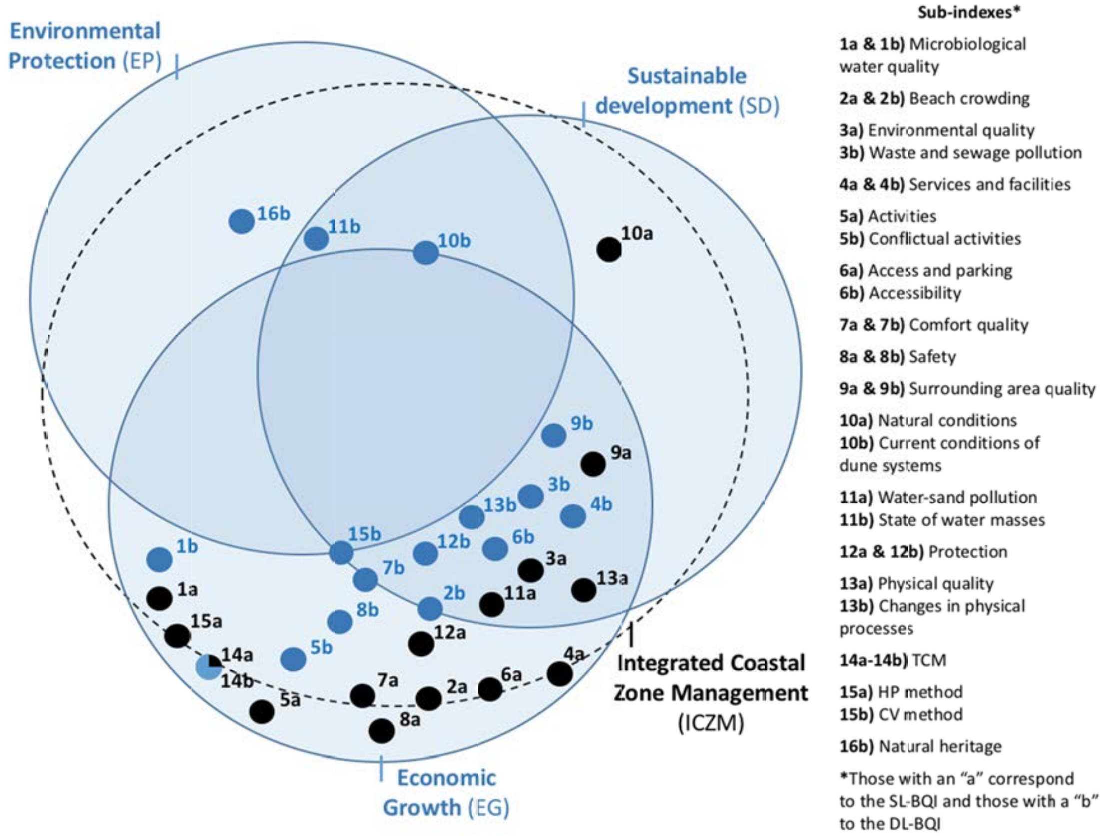

Figure 14. Positioning of sub-indexes in relation to the narratives observed. Letters "a" and "b", respectively, differentiated each sub-index number in SL-BQI and DL-BQI versions. Source: Own elaboration.

In this first development of the DL process, we should assert that sub-indexes moved from having a focus on EG (i.e., 1a, 2a, 4a, 5a, 6a, 7a, 8a, 14a and 15a), in some cases mixed with SD (i.e., 3a, 8a, 11a, 12a and 13a), or on SD alone (i.e., 10a), to being placed more to the center of the integration and to including EP narrative (e.g., 10b, 11b and

16b). We recall that the number of sub-indexes should not be directly related to the importance given to each narrative, but denoted our limitations on identifying and detailing certain processes/assets. Relying on sub-indexes responding to different narratives is indeed central to addressing the plurality of perceptions; however the assignation of importance should take place in further deliberative processes. For example, if decision makers are not aiming at the economic growth of a given beach, they should prioritize those sub-indexes that do not refer to the expansion of recreational activities, though less in number. Highlighting narratives and communicating DL-BQI results through dimensions, unlike the SL-BQI that targeted a global score, aimed at facilitating deliberation.

The ICZM narrative (the dotted circle) evolved from only being a recognition of three beach functions in the SL-BQI to an umbrella concept which, in the DL-BQI, aims at including all other narratives and relates directly to the overarching objective. We believe that, through the EPA, it may improve the issues of transparency, dialogue, inclusiveness and learning from past actions (Bremer, 2013), and widen the spectrum of assets and relations observed in the level of the DL-BQI. The new additions (as a sub-index or attributes) and the discarding of weighting and aggregation between sub-indexes partly acknowledged beach complexity and incommensurability. Addressing integration should be seen as an emblematic example of how pertinence was improved through the DL process, i.e., the main problem (in Figure 12) is now linked to the overarching objective in a more integrative tool for the analysis of the Catalan coast and, consequently, the formal system enabling such an analysis. An enhanced connection between problems and objectives is also reproduced in each dimension where the corresponding fundamental objectives (dimension level) and partial objectives (sub-index level) try to answer, respectively, particular and partial problems. Thus, a better fitness or function to purpose seems to be promoted (Nardo, et al., 2005).

It is noteworthy that the DL process predicts future developments of the DL-BQI, supported by the fact that each stakeholder might take a non-equivalent path to perceive and explain the different coastal situations changing over time. Integration might draw and negotiate a wider diversity of observable relevant attributes and relations for the object of analysis (Giampietro, et al., 2006; Bremer & Glavovic, 2013b), enhancing the perception of the system and the usefulness and pertinence of the assessment tool. To cite an example, in the case of the present work, the EP narrative was incorporated for the time that citizen platforms, federations of fisheries and social ambit were included.

The observed lack of integration (i.e., misbalance of narratives) behind the SL-BQI may be assigned to the Catalan coastal system itself as a consequence of the agreed deficient integration in the region, and to the research context in which it was developed. Theory and practice on beach management have been recommending tools (with few exceptions) that, primarily, prioritize the EG narrative above others (e.g. (Martí, et al., 2013; McLachlan, et al., 2013; Mir-Gual, et al., 2015)). For instance, a broad review of sandy beach literature (Nel, et al., 2014) indicated that the majority of conservation and management research places importance on understanding human impacts instead of strategies for conservation and management which, respectively, would possibly maintain the standard recreational model associated with the EG rather than integrate other alternatives. As a result, the majority of current programs do not intend to conserve beaches in a proactive way, but to manage and alleviate the different types of stress.

A tool for the assessment of all Catalan beaches should primarily integrate (and not neglect) all the potential objectives of management. However, not all objectives can be enhanced at the same time when various dimensions are considered (Munda, 2004). Thus, through the DL-BQI, we intended to offer the possibility of operating by means of four fundamental objectives separately (according to their corresponding dimensions, besides the wider Governance & Management). For example, focusing on easy accessibility (from Recreational Activity dimension) may negatively impact natural assets (from the Ecology & Natural heritage dimension) (Roig-Munar, et al., 2018), and the decision about which of them should be prioritized will depend on the deliberation at a local/regional level.

Though presenting different fundamental objectives, there is a probable chance of falling into two opposite beach management policies: a high quality of services and facilities, and environmental protection. This binary approach may not be the best scenario for sustainability of the Catalan coast, where beaches with a major tourist potential show the need for policies combining elements of both extremes. This mixed strategy could allow us to overcome the “resource paradox” (Williams & Ponsford, 2009). Here, (part of) society demands from municipalities more and improved services and facilities: these may (harmfully) impact beach ecology and natural heritage (Mir-Gual, et al., 2015), but also constitute a source of income to carry out initiatives to conserve natural assets and processes, e.g., actions for environmental protection, and consequently to sustain competitiveness (Dadon, 2018). In this manner, and because of local specificities, management should be centered on negotiation rather than consensus[15]. Accordingly, it would be worthwhile checking whether “intermediate” policy objectives, in which priorities could range from a high quality of services and facilities (for instance, it would include mechanical cleaning operations) to environmental protection (it would prefer manual cleaning which has less impact on the biological communities in the aerial part of beaches) (Roig-Munar, et al., 2005), might be established in practice, depending on the type of beach in question. In the deliberation process, the direction on which beach management should focus considering the aforesaid range relates to the importance assigned to each of three change drivers: “the quality services demand, the public use and enjoyment, and the environmental sustainability” (Dadon, 2018, p. 619). This proofing could be tested throughout the final steps of the double-loop depicted in Figure 9 (not treated in the present study): the assessment of the DL-BQI and the information for policy action, in which the sub-indexes could be measured in practice, analyzed and reported in order to aid management and governance.

[15] The Catalan government classifies beaches into urban (i.e., more permissive and catalyzer of services and facilities) and natural beaches (Gencat, 2016). This classification was criticized by some of the FG participants given that management alternatives would only focus in two opposites.

The new DL-BQI did not address all the problems listed by the stakeholders, but—rather—focused on those of excessive simplification. The reflexivity exercise (Kovacic & Giampietro, 2015) contributed to highlighting the choices and limitations of this model with respect to social and political targets. As in Garnåsjordet, et al. (2012), we suggest that the future development of other socioecological systems' assessment tools, particularly those targeting beaches besides the Catalan context (e.g., Botero, et. al. (2015); Lucrezi, et al. (2016)), should incorporate the whole DL chain reliant on a wide reflexive EPA, from the outset, if their capacity to aid political decisions is to be improved. Since these tools should respond to scenarios of complexity and uncertainty, we strongly believe that their updating, focused on epistemological and pragmatic plurality according to (coastal) socioecological dynamics (Bremer, 2013), could tackle scientific assumptions and contribute to adaptation, democratic legitimacy and transparency. Exploring the quality of assessment tools in this direction should replace the pursuit of truth (Funtowicz & Ravetz, 1993). Likewise, method adjustments are predicted in accordance with the resource limitations of each national, regional or local policies.

5. CONCLUSIONS

In this work, the DL process of learning was presented as a potential strategy to coproduce more useful and pertinent assessment tools for policy-making. Its applicability was tested by developing the steps of (re)selection, (re)definition and (re)production of an index for beach management. An expanded peer assessment (EPA) constituted the core of this process, throughout which the (re)refinements and (re)representations of Catalan beach processes and objectives were enabled, and the essential characteristics of socioecological systems (e.g., complexity and high dynamism) were incorporated.

The DL proved to be helpful in identifying the embedded problems of the Catalan coast, particularly the lack of an integrated beach management. In order to tackle these problems, we aimed at an enhanced beach management tool capable of establishing the minimum parameters that should be taken into account independently of political mandates, though enabling a negotiation between different dimensions and local specificities. We therefore evolved from the SL-BQI—which was constrained to a scientific view essentially associated with the EG narrative and, to a lesser extent, to the SD and ICZM—to co-building the observed system and its subsequent formalization into the DL-BQI. Room for improvement indicated by the whole set of narratives—EG, ICZM, SD, EP—were addressed here by the new measurement schemes. In short, we adjusted the overall and fundamental objectives of the DL-BQI according to the identified dimensions and related conflicts. More than modifying the former existing sub-indexes when needed, we included a wider spectrum of assets and processes through new sub-indexes and attributes, whilst highlighting the embedded choices.

Besides, the steps of the DL process approached in this study showed a potential for increasing usefulness by adjusting the represented system with the objectives of analysis, and pertinence by a more rigorous process for the production of information for policy. Respectively, it may have potentiated the epistemological and pragmatic quality of knowledge. Nevertheless, we reiterate that further developments of this endless dynamics should try to advance towards the non-addressed conflicts and uncertainties, though accepting that these would not ever be completely minimized. Also, we call for advancement towards the last steps of this strategy - the assessment and information for policy actions - in order to check its practical application and the further negotiation regarding the objectives of the overall process of management and governance.

Finally, it is noteworthy that, to date, the beach management field has proposed tools to incorporate and aid complexity and integration with a main focus on the theoretical level. The inclusion of more practical initiatives – e.g., the DL process - might develop these topics further through the widening of views and interests, and learning from past actions. In other words, a framework for the enlargement of (academic and non-academic) knowledge is set up. We, thus, recommend its application in future studies, coupled with the commitments made regarding the improvement of practices and transparency, and also with the action-intervals established by natural and political cycles.

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2.3| MULTI-DIMENSIONAL ASSESSMENT OF CATALAN BEACHES (SPAIN) FROM A PRAGMATIC AND EPISTEMOLOGICAL PERSPECTIVE

(Potential future) PUBLICATION 3

ABSTRACT

The science-policy interface for coastal and beach governance has been calling for quality scientific information to propose useful alternatives to the complex problems of the present, and to achieve sustainability. Much of the advancements in the beach management field have focused on the former, including past studies developed in Catalonia. Nevertheless, attention to the procedural way in which knowledge has been produced has not been usually paid. Hence, this work aims at developing and presenting an expanded reviewed assessment of the Catalan coast operationalized by means of the Double-Looped Beach Quality Index (DL-BQI), which was designed through an open process of learning. Such an enterprise also aids understanding of the level in which the narratives of beach management in Catalonia are unfolding in this territory, as well as the capacity of the DL-BQI on providing information for policy. A set of methods (i.e. fieldwork, geographic information systems (GIS), consultation of institutions and document review) and further analyses were employed to assess 96 representative beaches of the Catalan coast. Both the tool enabling the assessment – the DL-BQI – and its results were co-evaluated in a multi-stakeholder meeting. In general, Catalan beaches have been mainly conditioned to supply elements for the development of tourism and leisure, except for some beach types or locations. Different pressures resulted from this orientation, most of them negatively impacting ecological assets and natural heritage of beaches. The economic growth narrative, though predominant, showed itself to be obsolete for tackling complex coastal problems. A plausible alternative to be integrated in the regional coastal policy could potentially be the emphasis on the value of beaches as natural systems, as advocated, to a greater to lesser extent, by the narratives of sustainable development, environmental protection and integrated coastal zone management. Future DL-BQI updates should include more systemic environmental management procedures and uncertainties related to the practical application of the tool, in addition to highlighting the aforesaid condition of beaches as natural systems.

Keywords: Regional policy, beach assessment, quality of knowledge, expanded peer review, narratives.

1. INTRODUCTION

Especially across the last century, a central role has been assigned to science as a source of sound knowledge for policy actions to be taken (Khun, 1962). However, the complexity of the world in general, but especially the "wicked nature" (Rittel & Webber, 1973) of contemporary problems (e.g. climate urgency and global environmental change), have started to indicate that science alone cannot often provide satisfactory response to society needs (Sarewitz, 2004). The development of more sophisticated technical and methodological knowledge will only improve a limited part of knowledge quality in the decision-making processes (Funtowicz & Ravetz, 1990; Maxim & Van der Sluijs, 2011). If we expand the concept, as proposed by Funtowicz & Ravetz (1990), the quality of knowledge would embed the content of knowledge itself (substantive), the context of knowledge production or use (contextual) and the processes throughout which it is framed, produced, communicated or used (procedural) (Maxim & Van der Sluijs, 2011).

As in other coastal zones worldwide, Catalan beaches have been experiencing a myriad of complex problems, especially since the 1950s, such as human massification, habitat destruction, erosion or sea level rise; each one (and collectively) unfolding within context-specific characteristics. The response to it has been the production of several scientific contributions that have delved into the previously existing knowledge on regional beach management on bio-physical, social and socioecological processes, e.g. (Ariza, et al., 2008a; Ariza, et al., 2008b; Ariza, et al., 2010; Ariza, et al., 2012; Roca, et al., 2009; Roca & Villares, 2008; Sardá, et al., 2015; Lozoya, et al., 2014; Pintó, et al., 2014; Ballesteros, et al., 2007). Their common focus has been on the creation of technical, methodological and substantive knowledge for the context of Catalonia, almost completely neglecting procedural quality of knowledge in this subject.

The Double-Looped Beach Quality Index (DL-BQI) (Bombana & Ariza, 2019) – an index for a multi-dimensional assessment of the state of Catalan beaches – is distinguished from the precedent research. It was structured as a double-loop (DL) learning process that co-framed (within a wider group of peers) the current beach problems through questioning the underlying values and, thus, supporting the correction of previous shortcomings (Argyris, 1982). Overcoming shortcomings related especially to the treatment of identified scientific biases, the decrease of difficulty of certain measurement procedures, the consideration of non-commensurability between different beach dimensions and processes, the reporting of the main uncertainties and, consequently, the increase of democratic legitimacy of the tool for beach management in question (Bombana & Ariza, 2018; Bombana & Ariza, 2019). It was, thus, made possible the achievement of co-built aims (e.g. to draw attention to the socioecological heritage of beach assets and the beach in itself).

The synthesis involved in the development of indexes (i.e. a modeling process) implies the perception of an observed system (e.g. a beach) and the following tasks of encoding the relevant information about this system into a formal system (e.g. the model or the set of indexes), of inferring about this formal system, and translating what has been observed into current analyses and/or predictions (decoding process) (Rosen, 1993; Giampietro, et al., 2006; Kovacic, 2015). This process is grounded on pre-analytical decisions regarding who will observe such system (Rosen, 1993; Giampietro, et al., 2006; Kovacic, 2015). The concern about collectively reflecting and taking the appropriate pre-analytical decisions and properly modeling beach systems, is the motivation that led the authors to develop the DL-BQI. Enabling its construction and subsequent assessment, through expanded feedbacks, involved the integration of the main narratives[16] of the Catalan coast and the choices made by the peers.

[16] A narrative is here understood as how people explain in words what they consider significant and important in a universe of dynamic and interrelated assets, processes and scales (Allen & Giampietro, 2006).

Advancing further in the procedural quality of knowledge, in the present study, we developed a multi-dimensional assessment of the state of the Catalan coast by applying the DL-BQI in practice to 96 beaches representative of the Catalan coast. The main contribution of the study is the presentation and expanded review of the assessment, which allows for the identification of prioritization in the Catalan narratives of beach management. In parallel to that, the capacity of this tool for providing information for policy is also checked. Our work expands on previous studies on the subject in Catalonia (Ariza, et al., 2010) and elsewhere (more in Table 1), as it provides a widened regional assessment of beach systems by defining and relating dimensions, narratives, sub-indexes and their outcomes. The analysis of the current status of Catalan beaches (the observed and modeled system) that is presented here can be said to have mainly conformed a decoding process.

2. BACKGROUND

The call for science for policy – conceptualized as two spheres displaying different value systems and ways of perceiving the world – was first introduced in one of the first books dedicated to build the Integrated Coastal Zone Management (ICZM) Framework (Cicin-Sain & Knecht, 1998). In the first approaches, knowledge quality in which the enterprise was grounded (Cicin-Sain & Knecht, 1998), was mostly associated with substantive academic work, e.g. (Nobre, 2011; GESAMP, 1999). Interdisciplinarity and participation have been, since then, evidenced as guiding concepts with an increasing degree of theoretical and practical influence and constituted the ferment of the few complex systems approaches to the coastal zone developed so far (Vallega, 1999; Botero, 2013; Bremer, 2011). Knowledge for ICZM, placed in the framework of coastal governance, should be mobilized, produced and used through the acknowledgment and reciprocity of different epistemologies dialoguing within a common context, in which scientific insights are horizontally positioned as one further contribution to the process (Bremer & Glavovic, 2013a).

Classic literature has recommended the implementation of beach management within the broader umbrella of ICZM (Williams & Micallef, 2009), so that the phases of an ICZM cycle[17] should potentially be addressed by the first. In this context, one of the most important branches of studies in the field is the development of indexes and rating schemes to assess beach systems sustainability. Different studies have been carried out worldwide (see Table 12), most of them in relatively small study areas. Less abundant and usually focused on particular issues were the ones corresponding to regional initiatives which could aid for regional policy, e.g. (Peña-Alonso, et al., 2017; Peña-Alonso, et al., 2018).

For policy advice, assessments were capable of identifying the capacity of beaches for the development of quality leisure/tourism activities (e.g. quality of services and facilities), for infrastructure protection (e.g. buffer capacity from sea energy), and the state and trends of certain environmental aspects (e.g. waste), ecosystem functionality

[17] 1. Issue identification and evaluation, 2. Program planning and preparation, 3. Formal adoption and funding, 4. Implementation, 5. Operation, and 6. Assessment (Cicin-Sain & Knecht, 1998).

(e.g. beach surface) and natural/cultural heritage (e.g. ecological, scientific, and historical importance); nonetheless, none of them focused on identifying the embedded values and uncertainties.

Table 12. Beach assessments presented in different world contexts, the number of beaches observed and the main issues covered considering the following codification: R= Recreation, M = Morphodynamics, EEC = Ecology and environmental conservation, SC = Socio-culture, and MV = Monetary valuation.

Study	Case study	Nº. of beaches observed	Main covered issues
(Morgan, 1999)	UK	70	R
(Cervantes & Espejel, 2008)	Mexico, Brazil and USA	5	R, MV
(Ariza, et al., 2010)	Spain	6	R, M, EEC
(Ariza, et al., 2012)	Spain	6	MV
(Botero, et al., 2015)	Colombia	8	R, EEC
(Lucrezi, et al., 2016)	South Africa	7	R, EEC, SC
(Semeoshenkova, et al., 2017)	Italy	3	R, M, EEC
(Peña-Alonso, et al., 2017)	Spain	34	M
(Peña-Alonso, et al., 2018)	Spain	34	R

In this work, we present a multi-dimensional regional assessment in which 96 Catalan beaches were observed. Most likely, because of its condition of being an internationally claimed sea-and-sand tourist destination (Sardá, et al., 2009), this coastal territory may be one of the most studied worldwide. Through a quick search on the internet, we may find several works covering the state of beach assets and functions (Pintó, et al., 2014; Jiménez, et al., 2011; Garcia-Lozano & Pintó, 2018), beach users' profiles and expectations (Roca & Villares, 2008; Roca, et al., 2009), the state of and strategies for beach management (Breton, et al., 2000; Breton, et al., 1996; Lozoya, et al., 2014; Sardá, et al., 2015; Ariza, et al., 2016), the introduction of tools for beach management (Ariza, et al., 2010; Ariza, et al., 2012), etc. In spite of all the research, the presence of a plethora of conflicts (such as the biased focus on recreational activities, erosion, lack of institution integration, etc.), which regional and local tools and institutional practices have not been capable of properly addressing, show that beach management and planning activities implemented so far are not adequate for the sustainability of these socioecological systems over time (Ariza, et al., 2008a; Ariza, et al., 2016).

The assessment herein presented, was done through the lenses of a new paradigm for the ICZM: The Post-Normal Science (PNS) (Bremer, 2011; Bremer, 2013), in which quality of knowledge continues to be the main principle behind the production of scientific information but, adversely, is expanded to include multiple knowledge systems, posing uncertainty and plurality at the center of the analyses (Funtowicz & Ravetz, 1993). Beaches, as other coastal systems, are not fixed "objects," but processes constantly becoming something different (Wright, et al., 2019; Prigorine, 1983; Giampietro, et al., 2006; Farrell, et al., 2013), so that new ways of conceiving and treating an issue should be pursued in order to integrate their inherent complexity. The approach across which we incorporated this logic in practice is detailed below.

2.1. Previous work

In the series of three studies we carried out (Bombana & Ariza, 2018; Bombana & Ariza, 2019), the present one being the last, we improved and tested a previous beach management model set up for Catalonia: The Beach Quality Index (BQI) (Ariza, et al., 2010), which is composed of a set of sub-indexes to measure the quality of Catalan beaches. Because it was originally built through a single-loop (SL) learning process (spheres and down arrow in Figure 9 of Publication 2), it is now named the Single-Looped BQI (SL-BQI). It was designed and measured by an interdisciplinary group of academics and stakeholder feedback was very limited along the process. In contrast, aiming at checking and expanding the knowledge made available by the BQI, we focused in a double-loop (DL) pathway of learning (spheres and upper arrow in Figure 9 of Publication 2) which included an expanded peer review (EPA) (with academics and non-academics) for the reassessment of its values, practices and goals (Siebenhüner, 2002).

In practice, our previous two works addressed the (1) (re)selection and (re)definition of the SL-BQI sub-indexes and (2) the (re)production of these sub-indexes (first two spheres in Figure 9 of Publication 2) by posing context to this endeavor through the consideration of the main set of narratives used to explain objectives and processes of the Catalan coast (Figure 11 of Publication 2). Narratives were identified through a multi-stakeholder meeting, followed by the analysis of the main assumptions and shortcomings of the SL-BQI during the development of five focus groups (Bombana & Ariza, 2018). These deliberative sessions supported the expansion of the knowledge made available by the SL-BQI and, thus, based a further updated version of this model that considered four dimensions: recreational activity, morphodynamics, ecology and natural heritage, and beach economics (Bombana & Ariza, 2019). This is the reason why its improved version is hereinafter termed the Double-Looped BQI (DL-BQI) (Bombana & Ariza, 2019). As the EPA is the cornerstone of the complex system approach to the socioecological systems, it must be emphasized that it was the first time such an endeavor was carried out in the beach management field.

The focus of this third study is, consequently, to present the main outcomes of the multi-dimensional assessment of 96 Catalan beaches, enabled by the DL-BQI model[18] (Table 11 of Chapter 2), and the resulting information for policy (last two spheres in Figure 9 of Publication 2), wrapping out the whole pathway.

3. GENERAL APPROACH: JOINING THE ASSESSMENT OF THE DL-BQI WITH THE INFORMATION FOR POLICY ACTIONS

As mentioned, the present work focuses on providing a multi-dimensional assessment of the Catalan coast by applying the DL-BQI and shedding light to its potential use for further policy actions (stages 3 and 4 with the support of the upper arrow of Figure 9 of Publication 2). We, accordingly, applied the DL-BQI sub-indexes (Bombana & Ariza, 2019) to a representative part of the beaches of Catalonia and analyzed the outcomes

[18] This presentation of the DL-BQI does not include the economic valuation methods introduced in Bombana & Ariza (2019), because we have not been able to approach them in the following results.

(full details in Figure 15). The material and methods that this exercise were based on are advanced in sections 3.1., 3.2. and 3.3.

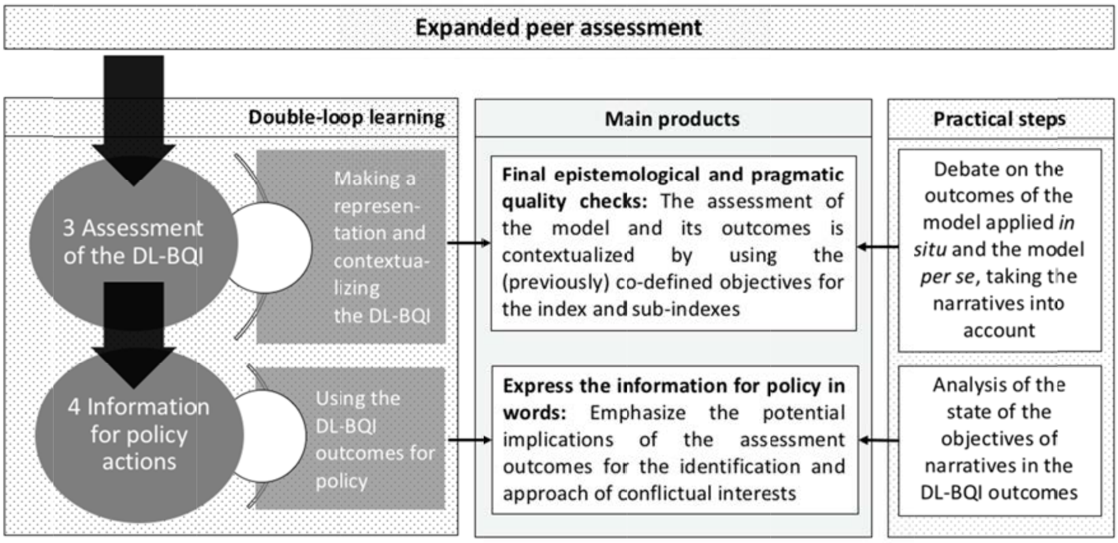


Figure 15. The methodological scheme applied for the assessment of Catalan beaches through the DL-BQI and the proposal of information for policy actions. Own elaboration based on Garnåsjordet, et al. (2012).

3.1. Assessment of the DL-BQI applied to the territory: Acquisition, processing, analysis and report of data

First, for the balanced application of the model – the DL-BQI – to the territory, we aimed at capturing the heterogeneity of the Catalan coast through the monitoring of a set of 96 (out of more than 800) selected beaches (Figure 16) identified in Catalonia (Garcia-Lozano & Pintó, 2018). To conceive the aforesaid set, we intended to observe at least one beach in each of the 68 Catalan coastal municipalities, as well as to include a balanced sample of the existing geomorphological coastal classes of Catalonia – i.e. abrupt, low and deltaic coasts (CIIRC, 2010) – and of the levels of urban development – i.e. urban, semi-urban and natural (Ariza, et al., 2008a) - randomly capturing short, medium and long beaches.[19]

[19] During the fieldwork, some adaptations *in situ* were required: From the 68 coastal municipalities, we were only able to measure/observe a number of 65 (excluding the municipalities of *Villasar de Mar*, *Gavà* and *Roda de Bará*), in which names identified by the *Llibre verd* (CIIRC, 2010) were not always coincident with reality. The set of beaches and classification according to beach type was, thus, adjusted *post* fieldwork and are presented in Appendix C together with the results of the DL-BQI.

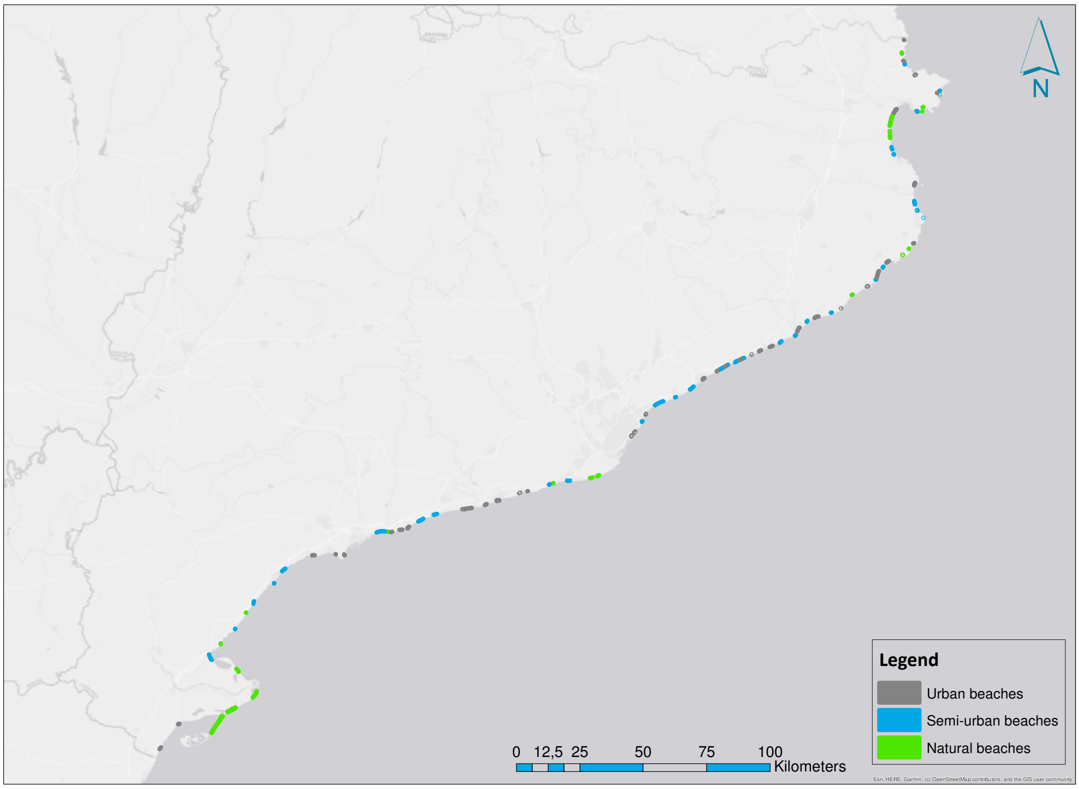


Figure 16. Location of the observed beaches in the Catalan coast. Source: Own elaboration.

3.1.1. Acquisition of data

Data for the aforesaid monitoring was acquired from a set of methods – fieldwork, geographic information systems (GIS), consultation with institutions and document review – provided in more detail below.

Fieldwork

Carried out in working days of the high season of 2016 (specifically between the summer months of July and August), each beach of a total set of 96 was visited once. The acquisition of data consisted of the observation or measurement of some sub-indexes' variables (Table 13), which was registered in fieldwork cards; photographs were also taken, which would later support checking potentially confusing data (due to errors of recording).

Table 13. Variables and the procedures throughout which were measured in the 2016 fieldwork.

Sub-index	Variables	Procedure
Waste and sewage pollution	*All*, except for episodes of short-term pollution or beach closure	Counting of water and sand waste, and observation of other variables (e.g. presence of oil), including the state of the sea promenade
Services and facilities	*All*, except beach guarding, bathing support and mobile signal	Metric measurement of distances and observation of other elements (e.g. type of seasonal facilities)
Conflictual activities	*All*, except for perception of robbery	Observation and counting of existing conflictual activities

[Continuation of Table 13]. Variables and the procedures throughout which were measured in the 2016 fieldwork.

Sub-index	Variables	Procedure
Accessibility	*All*, except for public transportation	Metric measurement of distances and observation of other elements (e.g. presence of bicycle lane)
Comfort quality	*Physical comfort*	Metric measurement of beach height, width and step, and observation of abrasive material and obstacles

Following that, in the high season of 2017, 10 beaches (of the three types of urban development level in the surroundings) were revisited over a whole day to support the calculations of the **beach crowding sub-index**. For that, photographs were taken hourly (from 9am to 7pm) of a transect of the beach that was considered representative of the whole beach, with its area measured by a tape-measure and recorded in a fieldwork card, together with information about the beach and date of observation.

Geographic information systems (GIS)

A shapefile of beach area demarcations was supplied by the Laboratory of Landscape Analysis and Management (Department of Geography, University of Girona). Next, for the **quality of surrounding area sub-index**, using the available online database of the Cartographic Institute of Catalonia (ICGC, n.d.), we were able to observe the *coastal defense work length* and *area of enclosed water table*; while using the land cover map of Catalonia 3rd edition v. 2 (2005-2007) (CREAF, n.d.), we observed the *impervious surface in the surroundings of beaches*. Attributes of *dune type* and *dune area* of the **current conditions of dune systems sub-index** were acquired from the maps of the dunes.cat website (Garcia-Lozano & Pintó, n.d.). As for the **natural heritage sub-index**, the cartography of the Catalan coastal habitats (1:1.500) (Departament de Territori i Sostenibilitat, 2014a) supplied the information regarding the *beach habitats' interest in conserving* and marine heritage. Also, the *marine heritage* obtained outside the Manual/Cartography of Coastal Habitats – i.e. those of seagrass (Dept. d'Agricultura, Ramaderia, Pesca i Alimentació, 2018) – the *natural protected areas* (Gencat, n.d.) and the *sites of geological interest* (in a 300m radius) (Dept. de Medi Ambient, 1999) were obtained.

Consultation of institutions, public databases and document review

First, by contacting involved institutions (in person, internet or telephone), we were able to obtain data on: 1) [**comfort quality sub-index**]: *weather variables*, from the Spanish Meteorology State Agency; 2) [**quality of surrounding** area sub-index]: the *impervious land use in the view shed of the beaches*, from the Laboratory of Landscape Analysis and Management (Department of Geography, University of Girona); 3) [**current conditions of dune systems**]: the *mean height and length of dunes*, *car parking/car tracks*, *built environment*, *density of the erosion pathway*, *dune breaches*, *invasive species* and *dune restricted plants*, from the same Laboratory. For also the current conditions of dune systems sub-index, information on *beach raking* procedures was acquired from coastal municipalities; and, 4) [**changes in physical processes sub-indexes**]: *coastal works developed in the last 10 years* in Catalonia, from the Coastal

Agency of the Spanish Ministry for Ecological Transition and from the Catalan Service of Coasts.

Other public database and documents were also searched and analyzed: 1) [**microbiological water quality sub-index**]: *All variables* (Annual Reports from the Catalan Waster Agency, ACA, 2016); 2) [**waste and sewage pollution sub-index**]: Variables of *short-term pollution episodes* and *beach closure due to pollution* (ACA, 2016); 3) [**services and facilities sub-index**]: Information on *mobile signal coverage* (Gencat, n.d.), *beach guarding* and *bathing support areas for handicapped people* (platges.cat); 4) [**accessibility sub-index**]: information on *public transportation* services (platges.cat); 5) [**comfort quality sub-index**]: *Jellyfish* variable (ACA, n.d.); 6) [**beach safety sub-index**]: *All variables* obtained through biddings specifications for the development of lifeguarding services (Gencat, n.d.); 7) [**state of water bodies sub-index**]: *All variables* (ACA, n.d.); 8) [**protection sub-index**]: *Damaged coastal infrastructure* from historical newspaper record for the period 2007-2017 (Diari ARA, n.d.; La Vanguardia, n.d.); 9) [**changes in physical processes sub-index**]: Data of beach area, berm and depth of closure (CIIRC, 2010)).

3.1.2. Processing, analysis and report of data

The data acquired for all sub-indexes was digitalized using Excel v. 15.23.2, using the DL-BQI structure (Bombana & Ariza, 2019) as a base. The following sub-indexes' variables demanded further calculations beyond acquisition: 1) [**beach crowding sub-index]**, the counting of beach users' attendance at beaches was done manually by observing the number of users in the photographs in a measured transect area. Results were extrapolated to the whole beach area calculated in the ArcGis software 10.6.1; 2)[**quality of surrounding sub-index],** in the same software as the former sub-index, the measurement tool of the *Mapviewer*, the proximity toolset (*buffer*) of the analysis toolbox and the zonal toolset (*zonal statistics as table*) of the spatial analyst toolbox were used/combined to calculate, respectively, the *coastal defense work against beach length, the area of water table enclosed by harbor and/or marine developments* (within 200m) and the impervious area (within 500m); 3) [**current conditions of dune systems**], the dune type and dune area were identified individually from the dunes.cat website (Garcia-Lozano & Pintó, n.d.); 4) [**natural heritage sub-index**], Miramon software v.8.1e., the beach area was combined to the cartography of coastal habitats through *Combicapa* tool, indicating the *most abundant habitat of the beach* (the respective *interest in conserving* was previously assigned by the Manual of the coastal habitats of Catalonia) and the *presence of marine heritage*; whereas also in the ArcGis v. 10.6.1, the *marine heritage* obtained outside the Manual/Cartography of Coastal Habitats (i.e. those of seagrass), the *natural protected areas* and the *sites of geological interest* (in a 300m radius) were identified individually; and, 5) [**comfort sub-index**], the Excel® software enabled the estimation of the *wet and dry slopes* of beaches taking the height and the width of the dry and wet area of beaches as inputs to the use of the *ASIN function* that, by applying trigonometric rules, calculates an angle (demanded in degrees); and, 6) [**changes in the physical processes sub-index]**, in the same software as the former sub-index, we approximated the proportion of the volume of soft works (when ensued) to the total beach volume by comparing the later to the beach area (longitude and width) multiplied by the beach height (the sum of the depth of closure with the height of the berm).

After, for **all sub-indexes**, the normalization of results into a range from 0 (worst performance) to 1 (best performance) (Ariza, et al., 2010) was carried out. The average outcomes of DL-BQI sub-indexes for each beach and for different possible aggrupations of beaches (i.e. by the classes of level of urban development, by Catalan provinces and, in the case of the safety sub-index, the level of risk) were underlined. Statistically significant differences were analyzed between these aggrupations for each sub-index, through the Kruskal-Wallis and Dunnett's tests in SPSS v.24. Finally, the average outcomes of sub-indexes for the groups of urban development level (i.e. urban, semi-urban and natural) were plotted in radar charts (Gomero & Giampietro, 2005), displaying the multi-dimensional performance in non-equivalent descriptive domains (Giampietro, et al., 2006). This way of representing scores allows for the assessment of the possible trade-offs between different processes (Garnåsjordet, et al., 2012).

3.2. Assessment of the DL-BQI outcomes through narratives: A final expanded peer assessment

The scores obtained for the DL-BQI allowed me to carry out a final epistemological and pragmatic quality check of the tool (Kovacic, 2015). We therefore organized a final multi-stakeholder meeting, held in Barcelona on March 29th of 2019, which was attended by 20 stakeholders of the Catalan coast from the governmental sector (Region, supramunicipal and municipalities), the academic sector (landscape processes), organized civil society (citizen platforms for environmental protection and education and the Catalan Federation of safety and rescue) and, the private sector (an environmental consulting firm). The aims of this whole-day session were:

1. To verify the progress of the DL process on advancing in the DL-BQI (presented by Bombana & Ariza, 2019);
2. To check the capacity of the DL-BQI outcomes on representing the reality of the Catalan coast and, thus, the main perspectives and objectives of the aforesaid stakeholders;
3. To understand the implications of the DL-BQI outcomes for the stakeholders and for policy actions.

The dynamics began with a brief explanation of our study, the development of the DL-BQI and its measurement to 96 Catalan beaches. In practice, we divided the total number of assistants into 3 heterogeneous groups, where in each of them, we approached 2 to 5 DL-BQI sub-indexes[20] and corresponding outcomes in 12 representative beaches of the Catalan coast (Figure 17). Graphs and photographs of these beaches were used to aid the debate, as well as cards that were filled out as arguments were being discussed. Finally, through a spokesperson for each of the

[20] Due to limitations of time and number of participants, three sub-indices – i.e. comfort quality, beach safety and quality of surrounding area - could not be approached in the final MS-meeting.

groups, the participants summarized the main ideas of their respective debates in a final plenary session.

Figure 17. One of the sub-groups of the MS-meeting discussing the sub-indexes of services and facilities, accessibility and beach crowding. Source: Paula Rodríguez Villanueva.

All the gathered information was used to set final adjustments in the DL-BQI model and highlight shortcomings and suggestions for further developments, which allowed for the aforementioned epistemological quality check. Also, through the discourse of stakeholders, we were able to assess the level at which the different narratives are currently unfolding in the territory. For instance, the stakeholders linked the generalized accessibility to all types of beaches to a democratic practice (narrative of sustainable development) and, in some cases, a promotion of touristic activities (narrative of economic growth) that usually encourages natural heritage depletion (contrary to the environmental protection narrative). Approaching a level of agreement between the outcomes and objectives of narratives enabled me to check the pragmatic quality of DL-BQI.

3.3. Information of the DL-BQI outcomes for policy actions

Even though we do not directly participate in the sphere of decision-making, we advanced in this point by defining and narrowing down the policy implications of the DL-BQI scores. That is, first specifically regarding the DL-BQI outcomes, we underlined the average final score of the sub-indexes for each beach, and discussed them according to different possible groupings of beaches (e.g. according to the urban development in the beach and surroundings). Secondly, we presented a brief explanation, based on the DL-BQI outcomes, of how narratives are currently being addressed by beach management actions. Both sets of information for policy supported the illustration of the present assessment of the Catalan coast and, hence, aided for the identification of the main implications of the contemporary policies and, particularly, the conflictual interests.

4. INFORMATION FOR POLICY: RESULTS AND DISCUSSION OF THE DL-BQI AND OUTCOMES

4.1. A final extended peer review of the DL-BQI model

In first place, the debates held indicated that the DL-BQI model indeed presents a potential to integrate a wide variety of aspects and processes of Catalan beaches, coupling with its overarching objective of transparently capturing the state of different beach processes in Catalonia (Bombana & Ariza, 2019). The MS-meeting participants expressed the following main concerns, which are transversal to the whole DL-BQI structure: 1) Beaches should be highlighted, primary, as natural systems, 2) Wider environmental management procedures should be integrated (e.g. the whole cycle of waste production, collection, transport, treatment and disposal) and 3) Attention should be paid to the potential uncertainties originating from the interpretation of the sub-indexes results, which were designed for the scale of Catalonia, in the municipalities.

Deepened by this analysis, the epistemological quality test of the DL-BQI sub-indexes allowed me to adjust these sub-indexes to stakeholders' demands, when possible (first column of Table 14), e.g. if there was data available for carrying out an assessment of a potentially updated DL-BQI sub-index. If not, adjustments remained as future recommendations and discussions (last column of Table 14). This updated DL-BQI, presented in Appendix B, was the set on which we based the assessment and information for policy discussion, presented in sections 4.2. and 4.3.

Table 14. Main highlights – introduced claims and, future changes and discussion – of the analysis of the DL-BQI sub-indexes by the stakeholders.

Sub-index	Introduced stakeholder claims	Future changes and discussions
Microbiological quality of water	Short-term pollution episodes were included in the calculation	-
Beach crowding	-	Measurements should be carried out on weekends (higher user attendance) and consider, instead of the urban development, the type of use (e.g. if touristic or residential) and/or the location of accesses in the surroundings
Waste and sewage pollution	Natural waste attributes (in water, sand, and also jellyfish) were excluded because they should be accepted by users as embedded elements of the beach	Observations should be developed twice in a day, consider the geomorphological type of beach (deltaic, abrupt, etc.) or the province in which it is located since transparency and water color may be influenced by the type of sand, and include differentiations between natural and artificial odor and specifications of human solid waste (e.g. type and size of plastic)
Services and facilities	-	The supply of services and facilities should be adapted to beach length and crowding expectancies as well as integrate the actions of an wider management cycle of some of them, e.g. instead of setting fixed distances for garbage cans, the approach should focus on the identification and classification of waste, allocation of garbage cans for storage according to beach length and crowding (the more crowded, the higher the use of garbage cans), transportation and final destination
Conflictual activities	-	Since users' behavior changes constantly in time and according to beach particularities, observations should be made in different hours of the same day and have the support of local institutions, e.g. at Costa Brava, motor ships that dock directly in some beaches are common, making appropriate a future differentiation of sailing with or without a motor (e.g. *kayaks*, *paddle surf*, etc.)
Accessibility	-	Strategies to limit attendance to beaches depending on (over) crowding values were suggested, instead of penalizing a good road network/structure, so that handicapped people could be included; and, to avoid the use of beaches as an alternative to marinas in which boats and other maritime vehicles can be docked, a limited accessibility by boats and other aquatic transportations should also be discussed
Current conditions of coastal dune systems	-	How should the wind transport potential and the occurrence of dune management actions (e.g., management and reconstruction of dunes with *Amophila arenaria*) be integrated to this sub-index, given that there are potential contributors to enhance dune systems' conditions

[Continuation of Table 14]. Main highlights – introduced claims and, future changes and discussion – of the analysis of the DL-BQI sub-indexes by the stakeholders.

Sub-index	Introduced stakeholder claims	Future changes and discussions
State of water bodies	-	Change the scale of the assessment from water bodies (current scale) to beaches
Natural heritage	Inclusion of natural protected areas and other type of marine heritage (e.g. *herbassars*)	Include new attributes (e.g. nesting areas), review weighting given to different attributes (e.g. interest in conserving) and methods (i.e. advance/ detail in the geological interest), and, consider the naturalization efforts in the context of high urbanized systems, such as the municipality of Barcelona
Protection	-	Establish relations between the method applied and the risk components: hazard, vulnerability and exposition, e.g. the consideration of beach orientation, grain size and height of the berm
Changes in physical processes	Only beach nourishment projects carried out with sand from outside filling areas were considered, given that those made with sand from surrounding areas, could be impacting biological communities (such as burrowing of benthonic fauna, Peterson & Bishop 2005) and have other effects, but most likely would not cause changes in the physical processes of beaches, since they refer to sand presenting similar grain size	Check the suitability of including nourishment projects carried out at the municipal level and other types of engineering works

The exercise of acknowledging adjustments – in this case, of four sub-indexes (i.e. microbiological water quality, waste and sewage pollution, natural heritage and changes in physical processes) – and future advancements for the whole DL-BQI set, reiterated that scientific knowledge and related tools will possibly always be based on assumptions and embedded uncertainties, even after a process aiming to produce a higher quality of knowledge. That is to say, the more you continue to expand the assemblage of knowledge, new considerations emerge and rooms for improvement are (again) underlined, reiterating gaps inherent to the study and representation of complex systems, particularly due to methodological and epistemological uncertainties. Methodological uncertainties are those that originated from the choice of material and methods capable of representing systems' assets and process (e.g. suggestions on modifying the period of time in which crowding should be measured), while epistemological uncertainties come from our limited ability to completely understand the structure and functioning of the aforesaid complex systems, such as beaches (e.g. the inclusion of local managers/institutions capable of indicating new types of conflicting activities not identified yet could enhance the knowledge about these activities) (Funtowicz & Ravetz, 1990; Kovacic, 2015). In an endless dynamic, further DL processes would potentially address these uncertainties, though not fully minimize them, especially in the case of the epistemological ones.

4.2. Assessment of the Catalan beach systems through the DL-BQI

4.2.1. The DL-BQI results

In this section, we introduce the outcomes of the DL-BQI sub-indexes for the three beach types (Figure 18), whereas the average scores of DL-BQI sub-indexes for each beach can be found in Appendix C. Considering that scores from 0 to 0.50 indicate bad performance, 0.51 to 0.75 a moderate performance and 0.76 to 1 as good, in general, Catalan beaches presented a moderate to good performance for the total set of the DL-BQI. The analysis by sub-indexes highlighted that the worst average outcomes unfold in the **current condition of dune systems sub-index** (0.40). Following that, moderate average outcomes are observed in the sub-indexes of **accessibility** (0.54), **beach crowding** (0.56), **natural heritage** (0.59), **quality of surrounding area** (0.60), **safety** (0.66), **comfort** (0.68), **services and facilities** (0.69) and **conflictual activities** (0.75); and good outcomes in the sub-indexes of **waste and sewage pollution** (0.77), **state of water bodies** (0.81), **changes in physical processes** (0.90), **protection** (0.94) and **microbiological water quality** (0.98). Significant differences were observed between beach types in the sub-indexes of accessibility ($p < 0.01$; KW test X^2 16.54), quality of surrounding area ($p < 0.01$; KW test X^2 46.73), current conditions of dune systems ($p < 0.05$; KW test X^2 7.96) and protection ($p < 0.01$; KW test X^2 11.04); while, between provinces, they were observed in the sub-indexes of waste and sewage pollution ($p < 0.05$; KW test X^2 6.82), comfort quality ($p < 0.01$; KW test X^2 29.09), state of water bodies ($p < 0.01$; KW test X^2 22.21) and changes in physical processes ($p < 0.01$; KW test X^2 9.47). These differences are further deepened in the following discussion.

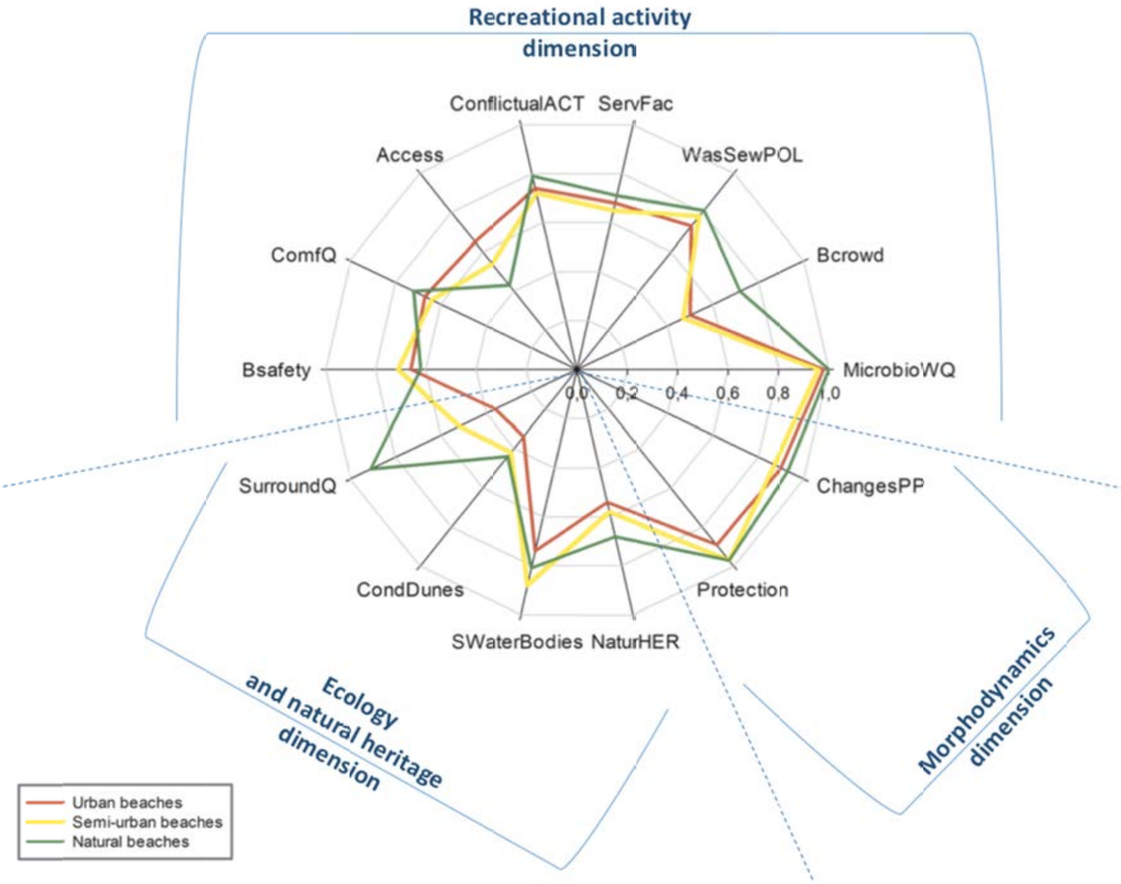


Figure 18. Average scores of DL-BQI sub-indexes in the three dimensions – Recreational activity, Morphodynamics and Ecology and Natural Heritage – according to the three beach types: Urban (n=40), Semi-urban (n=36) and Natural (n=20). Sub-indexes: MicrobioWQ = Microbiological water quality, Bcrow = Beach crowding, WasSewPOL = Waste and sewage pollution, ServFac = Services and Facilities, ConflictualACT = Conflictual activities, Access = Accessibility, ComfQ = Comfort Quality, Bsafety = Beach safety, SurroundQ = Quality of surrounding areas, CondDunes = Current conditions of dune systems; SWaterBodies = State of water bodies, NaturHER = Nature heritage, Protection, and Changes PP = Changes in physical processes. Source: Own elaboration.

First, we observed bad average scores of the **current conditions of dune systems sub-index**, particularly in the case of urban beaches, agreeing with former assessments carried out in Catalonia (Ariza, et al., 2010; Pintó, et al., 2014; Garcia-Lozano & Pintó, 2018) where these coastal natural assets displayed a general bad state of conservation. The significant differences found between beach types ($p < 0.01$; Dunnett's test) are disclosed in the results of urban (0.34) and natural (0.44) beaches. The main causes to that are anthropic – such as, deflation channels caused by human walking on the dunes, usually directly proportional to users' crowding, and by mechanical beach cleaning – revealing fragmentation, notably in tourist beaches (Pintó, et al., 2014; Garcia-Lozano & Pintó, 2018).

The wide accessibility to most parts of the Mediterranean coasts and their subsequent overcrowding (Roig-Munar, et al., 2005) are somewhat confirmed by the current results of the corresponding sub-indexes, respectively, **accessibility** and **beach crowding sub-indexes**. For accessibility, differences were very significant between urban and natural beaches ($p < 0.01$; Dunnett's test) and, significant between urban and semi-urban beaches ($p < 0.05$; Dunnett's test). In particular, urban beaches presented the best valuation for accessibility among beach types (0.65) and, inversely proportional, bad scores for crowding (0.50); denoting a general ease of all types of access for users (Roca & Villares, 2008; Roca, et al., 2009; Ariza, et al., 2010). On the other hand, semi-urban beaches deployed the worst score for crowding (0.47) (Roca, et al., 2009; Ariza, et al., 2010) and an almost bad performance for accessibility (0.54), which, by the structure of this sub-index for semi-urban systems, could also denote easy and generalized car access. Natural beaches had the lowest score for accessibility (0.43) due to a general encouragement of car access, even in the context of natural surroundings. Not contributing to the increase of scores was, as well, the general lack of infrastructure and services for bicycles and public transportation. Scores for crowding were the best in this type of beach (0.72).

As expected, natural beaches that are wrapped in less urban surroundings, had better scores for sub-indexes of natural heritage and quality of surrounding area than semi-urban and urban beaches. Despite that, regarding the **natural heritage sub-index**, all beach types exhibited efforts being taken for the natural heritage to be conserved. Even some urban and semi-urban beaches (e.g. *Empuriabrava, de les Barques, de l'Estació, Llarga de Cubelles* and *de la Punta del Riu*), which are located in highly transformed surroundings (as seen in respective average scores for quality of surrounding area), presented high scores for this sub-index. The given examples of urban and semi-urban beaches had in common the presence of marine heritage and the location next to natural protected areas, which increased their performance beyond simply an interest in conserving the most abundant habitat. The general bad performance of the interest in conserving beach habitats (0.32) may be related to fact that the main analysis observed the primary constitution of the beach (i.e. its most abundant habitat, such as *supralittoral* sand beaches without vegetation, or coarse sand and gravels without vegetation at the *midlittoral* stage). Usually, when it comes to approaches such constitution, we should recall that beaches are understudied systems that have received less attention (and lower valuations) when compared to other coastal habitats (such as rocky shores and wetlands) (Defeo & McLachlan, 2005; Barbier, et al., 2011). Some stakeholders highlighted that beaches as a whole should be preserved, regardless of the habitats present in them. For instance, *De Buda* beach, located in the *Delta de l'Ebre* natural park, in spite of being the only beach to which access is restricted (an authorization is needed to do so) because of its ecological importance, it deployed a final bad performance (0.36). The observation of natural protected areas, together with the integration of particular marine heritage and areas of geological interest, helped to increase the final outcomes for this sub-index. It can be said, at any rate, that in cases like *De Buda* beach, the sub-index did not capture the importance of the natural heritage well, probably because there are elements or processes that are not being (properly) considered. Stakeholders advised the inclusion of other beach elements/processes in further developments of the DL-BQI (Table 14).

As to the **quality of surrounding area sub-index**, the results echo with the conclusions of other studies that called attention to the high level of urbanization of the Catalan coast (Marcos, et al., 2013; Ecologistas en Acción, 2019); e.g. in 2013, a Greenpeace report highlighted that Catalonia displayed the second most urbanized coast of Spain with a 44% of impervious surface of the coastal strip (Marcos, et al., 2013). Indeed, urban and semi-urban beaches located in the province of Barcelona had, in their vast majority, a bad performance for this sub-index. It is also noteworthy that the small number of urban beaches displaying moderate to good outcomes are located in the limit of defined natural protected areas (e.g. *Cap de Creus* Natural Park), which may have contributed to buffering the negative impacts in the landscape, generally affecting the Catalan coast in their vicinity. The results observed are directly proportional to the very classification of beach type, increasing importantly the quality from urban (0.36) and semi-urban (0.52), the most urbanized shores, to natural (0.91) beaches. Very significant differences ($p < 0.01$; Dunnett's test) were identified between urban and semi-urban beaches, urban and natural beaches, and semi-urban and natural beaches. In this line, geographically, some differences were detected between the province of Barcelona (0.36) and, Girona (0.65) and Tarragona (0.59), probably as a consequence of the fact that the first has the lowest and highest proportions of, respectively, natural and urban beaches observed.

The scores of the **beach safety sub-index** showed a moderate average performance, whereas significant differences ($p < 0.05$; KW test X^2 6.39) between the levels of risk assigned for each beach were also observed, i.e. between the beach groups presenting high (0.63) and medium (0.72) levels of risk. The low level (0.90) of risk was not considered in this test because it was only observed in one of the beaches studied. Also, a significant difference between the province of Girona with Barcelona ($p < 0.05$; Dunnett's test), and a very significant difference to the first province and Tarragona ($p < 0.05$; Dunnett's test) were found. Barcelona (0.71) and Tarragona (0.76) presented almost good to good average scores, while Girona (0.58) presented almost bad average scores. This is mainly because 42% of the observed beaches located in the Girona province did not present safety services.

Within the moderate average performance of the **comfort sub-index**, we should emphasize that very significant differences ($p < 0.01$; Dunnett's test) between the province of Tarragona (0.69) and the others were observed due to the meteorological and geomorphological characteristics of the Catalan coast. The worst performances of Girona (0.59) and Barcelona (0.62) could be justified by the fact that lowest water and air temperatures, which are not well valued for comfort quality, are expected to be found as we move from south to north in Catalonia (CIIRC, 2010). For the particular case of Girona, it is noteworthy that it is the province presenting the highest proportions of rocky or steep beaches, respectively, exhibiting lowest widths, more abrasive material and obstacles or steeper slopes (commonly associated with cliffs) (CIIRC, 2010); all features penalized by the sub-index in question.

Both the almost good average performances of the **sub-indexes of conflictual activities and services and facilities** did not present significant differences between beach types or provinces. However, we may underline differences in the type of **conflictual activities** according to beach types, though important percentages of music/noise (between 35 and 48%) was observed in all of these types. To cite some instances, sports outside specific areas were mainly observed in urban (87.5%) and semi-urban (58%) beaches, given that they are conditioned to the existence of demarcated areas for sports (usually present in these types of beaches) and also more probable in crowded environments; while pets were observed especially in semi-urban (44%) and natural (45%) beaches, partially because control is usually softened from urban beaches to the ones in question. Ariza, et al. (2010), similarly, found that pets were observed more in semi-urban than urban beaches; and, in contrast to our study, saw few conflictual activities in the group of beaches they analyzed.

Regarding **services and facilities**, average results were moderate and similar to all beaches, indicating a proportional effort from local managers in the three beach types. However, such as that which occurred in the former sub-index, depending on the beach type, certain services and facilities were more prioritized than others. In the case of urban beaches, a general good performance was observed in the presence of guarding services (0.78), in showers and footbaths (0.81), which were mostly separated in the best distance defined for this type of beach (i.e. < 150m), and in the supply of bathing support areas for handicapped people (1.00). In semi-urban beaches, the last two were also valued as good (respectively, 0.79 and 0.93), though the best performance of showers and footbaths refers to their disposition only at beach entrances, together with the non-existence of facilities for children (0.86) and the disposal of information, at least, at beach entrances (0.81). These last two services and facilities presented a similar good performance in natural beaches as well (respectively, 0.95 and 0.89), though for this type of beach, information is better valued when placed only at beach entrances, jointly with the absence of parasols and hammocks (0.84) and of sports facilities (0.79). A general good mobile signal (0.86) was observed in all beach types. Contributing to decrease the average scores, the urban beaches generally exhibited open parasol/hammocks (0.24), while in semi-urban beaches, garbage cans (0.26) were disposed usually on the sand, in addition to those at entrances (the condition for the best performance). In the case of natural beaches, the same was observed about garbage cans (0.23), and there was a general lack of guarding (0.32). No significant differences were found between the offer of services and facilities and beach length, countering the idea that their supply is more difficult the longer the beach is (Ariza, et al., 2010).

The results of the **waste and sewage pollution sub-index** showed relatively good scores, agreeing with results found in a similar analysis of a small group of Catalan beaches (Ariza, et al., 2010). Usually worse performances were associated with the presence of other waste types (foam, tar, oil or odor and short-term pollution episodes), rather than solid human waste. The average good results of the latter (0.82) can be partially explained by the existing widespread practice of beach raking in Catalan beaches (in 89% of studied beaches). Significant differences were not found between beach type. In the case of the **state of water bodies sub-index**, though all presented a good average score, very significant differences ($p < 0.01$; Dunnett's test) were found between the province of Girona (0.97) with Barcelona (0.66) and Tarragona (0.75), probably due to the location of some beaches of these last two provinces in highly dense urban areas (e.g. Metropolitan area of Barcelona and Tarragona bay), in which the discharge of high levels of dissolved inorganic nutrients and/or high levels of chlorophyll (phytoplankton) from rivers with dense concentrations of urban and industrial uses (ACA, n.d.) is usual.

The good performance of the **changes of physical processes sub-index** was explained by the fact that only 17% of Catalan beaches presented some kind of nourishment project carried out in the last 10 years, which negatively account for the anthropic changes in question. Beach type categorization did not significantly affect the results, but the analysis by provinces did so. Very significant differences ($p < 0.01$; Dunnett's test) were detected between Barcelona (0.78) and Girona (0.99). The province of Barcelona presented the lowest scores – i.e. the most altered beaches by nourishment projects – and, inversely, Girona the highest ones. The better performance of the later province could be somewhat explained by an important proportion of pocket beaches in which headlands function as a natural protection from sea energy and the maintenance of the volume of sediments is guaranteed as they constitute a closed sediment cell (Jiménez, et al., 2011). In this context, changes in shoreline are due to transference of volumes from one part of the waterline to another, rather than to erosion trends (Jiménez, et al., 2011), so that there must be a lower need for beach nourishment projects. Relating these sub-index results to the comfort quality sub-index, the bad performance of the province of Barcelona in the physical attributes (0.43) may be partially explained by the deposit of fill sediments (nourishments) that, especially when done in the upper beach, leads to changes (usually, increases) in the original beach width, slope and step (Greene, 2002). The increase of these attributes is directly proportional to the worsening of scores in this sub-index, except in the case of very narrow beaches and very abrupt wet areas. For example, from 4º to 6º, beach slope is considered moderate, and from 6º onwards, bad.

Regarding the **protection sub-index**, few observed beaches (16%) had scores that reflected damaging events or impacts, though some of them had specifically critical performances. For instance, the *S'abanell* beach had its sea promenade harmed six times in the last 10 years, and its neighboring beach (i.e. *La Punta de la Tordera*) also presented feebleness in its protection capacity, both being part of the *Delta de la Tordera,* where the risk of erosion/inundation is high (Guillén, 2008). Significant differences ($p < 0.01$; KW test X^2 11.04) were observed between beach types. Natural (0.97) and semi-urban (0.97) beaches displayed equally better performance than urban (0.89) beaches. We believe that urban systems exhibited the lowest average scores because most of them presented sea promenades or other infrastructures parallel to the beach, which are potentially subject to sea energy.

Finally, in reference to the criteria defined in the Directive 2006/7/EC, beaches in Catalonia displayed the higher performance possible for the **microbiological water quality sub-index**, except in a few beaches (12.5%). This fact may be explained by the generalized development of sewage treatment in the last decades in Catalonia (Ariza, et al., 2010). Those beaches with lower scores are located near to small river mouths and/or marine outfalls, subjected to sewage/rainwater discharges. In this case, scores reflect affectations by short-term pollution episodes, mostly related to non-regular rainfall (ACA, 2016).

4.2.2. The assessment of the narratives of the Catalan coast according to the DL-BQI outcomes

In a general sense, from the DL-assessment, we may assert that beach management in Catalonia have been answering primarily to the demands expressed by the economic growth (EG) narrative and, to a less extent, to the sustainable development one (SD), followed by the one advocating for environmental protection (EP). The preponderance of economic activities associated with touristic/leisure activities have already been underlined by other works (Ariza, et al., 2008a; Bombana & Ariza, 2018). In many areas involving natural beaches and other few exceptions in semi-urban and urban beaches, though, the traditional conception of beaches as places designed for the development of recreation and to protect coastal infrastructure (James, 2000; Ariza, et al., 2008a) has not been widely applied and beaches have also been valued as natural systems. Individually for each narrative, this is reviewed below. In this discussion, it is noteworthy that the comfort sub-index was not included, because it refers to beach conditions not directly influenced by management actions.

Economic growth (EG)

The hegemony of this narrative is seen in the prevalent management actions designed (almost exclusively) for the development of touristic and leisure activities at beaches, aiming at the satisfaction of beach users, or part of them, above other stakeholder groups. The outcomes of some DL-BQI sub-indexes agreed with the former statement, independent of beach type, including the **microbiological quality of water, waste and sewage,** and **accessibility and safety** sub-indexes. Both **microbiological quality of water** and **waste and sewage** sub-indexes presented very good performances, indicating a widespread concern for providing good quality of water for bathing and also good water and sand cleaning for users' satisfaction. The moderate average score of the **accessibility** sub-index indicated a wide accessibility to beaches, mostly related to a general ease of access by car (even in the case of natural surroundings), which promotes the attendance of a mass of potential users. Similarly, some sub-indexes' outcomes expressed EG actions on mostly urban and semi-urban beaches, e.g. **beach crowding and services and facilities** sub-indexes. For these types of beach, general overcrowding may indicate that the minimum requirements of what users expect to find at beaches and surroundings are being disposed/presented at these systems (e.g. good water quality, services, accessibility, etc.). We assume that a lower attendance of users would be more plausible if the contrary was true regarding such requirements. In fact, a moderate supply of **services and facilities** in those, including **safety** (in all types of beaches), was detected. On one hand, the **protection** sub-index demonstrated that few beaches (16%) did not present the minimum capacity to protect monetarily valued coastal infrastructure. On the other hand, the **changes in physical processes** sub-index denoted the intention of maintaining the beach area for the development of leisure and touristic activities and the protection of infrastructures, in some punctual cases (17% of beaches), given that soft engineering works have been undertaken. A close relationship to what is advocated by the present narrative was, thus, perceived for also this last sub-index.

This focus on touristic and leisure activities has contributed to impact beach systems, due to, at least, four main stressors: nourishment, recreation, cleaning, and coastal development and engineering works (Defeo, et al., 2009). A clear instance is the fill of sediments of usually (slight) different grain size and type that is known to impact beach ecological communities (e.g. turbidity causes stress in marine fauna) and morphological processes (e.g. changes in the beach profile alter its interaction with waves and other hydrodynamic processes) (Peterson & Bishop, 2005; Pilkey & Dixon, 1996; McLachlan & Brown, 2006). Another one is the understanding that the most sea storm-impacted coastal infrastructure are sea promenades, which are developed to satisfy leisure and tourism demands and are known to disrupt natural dynamics of dune-beach systems (e.g. cross-shore sediment transportation) (Boda, 2018b). Thus, the bad to moderate results of the sub-indexes of current conditions of dune systems, quality of surrounding area (except for natural beaches), natural heritage (mainly for urban and semi-urban beaches) and, in punctual cases, of changes in physical processes and protection supported the observance of the former in Catalonia. They showed the deterioration of landscape, vegetated and sandy areas, particularly dunes, highlighting that management strategies other than those linked to EG (such as, environmental protection of ecological communities) have been generally de-emphasized.

Sustainable development (SD)

This narrative, though not preponderant, was detected when DL-BQI outcomes indicated that beaches were appreciated by managers as both public and natural spaces to be conserved throughout time, as well as when management differentiations were perceived depending on the type of beach. For example, the absence or minimal supply of services and facilities mostly only in natural beaches, as shown by the results of the corresponding sub-index, may mean that, probably, in this type of beach, mass tourism and leisure have been substituted by other types of leisure that are more in tune with their condition as natural systems (e.g. naturism), or even environmental protection. As expected, due to the proper classification of beach types according to different levels of urban development in the surroundings, the quality of surrounding area sub-index showed very significant differences between the urban, semi-urban and natural systems, which may indicate differentiated territorial management in this sense. The influence of territorial planning measures (e.g. natural protected areas) meant to preserve the coast as a natural system was even noticed in some particular urban beaches, i.e. the best performances on quality of surrounding area of this type of beach were identified in those located close to natural protected areas. It is also possible that the widely good performance of the protection sub-index, especially in natural and semi-urban beaches, was linked to the non-existence of coastal infrastructure in the first line of the beach, which can be interpreted as an action of conservation of natural assets, especially in sandy beaches where a sand-dune system is deployed. Finally, the observation of conflictual activities in almost all beaches helped to reiterate the public condition of beaches advocated by the present narrative, since these systems are a place to develop the myriad of the former. The conflictual character of the activities, however, is what underlines the need for regulations, especially those aimed at good coexistence between beach users.

Environmental protection (EP)

This narrative, related to those outcomes indicating good state of ecological processes/assets or direct environmental protection actions, has been marginally pursued. Remembering that the EP and SD narratives are somewhat similar as to what regards the highlight of the natural value of beaches and the consideration of local specificities, although they differ mainly in the level of permissiveness of human activities (Bombana & Ariza, 2019), a certain parallelism of the present study to the SD discussion arose. That is, actions to primarily enhance the environmental protection of beaches and surroundings to the detriment of other objectives were observed in particular beach types or areas of the territory, such as the minimization of services and facilities in natural beaches and the existence of natural protected areas on the Catalan coast. The same is true in the marine realm of the whole territory: the moderate to good state of water bodies and the increase of scores of natural heritage in some beaches due to marine heritage showed a certain level of marine environmental protection, in spite of the impact of landward management on marine assets in highly dense urban areas.

Integrated Coastal Zone Management (ICZM)

Lastly, the discussions of the aforementioned narratives highlighted the importance of taking into account the ICZM narrative in the science-policy interface. Potentially, through the lenses of coastal governance, it would integrate the negotiation of the priorities and interests of other narratives, enhancing inclusiveness, integration and knowledge quality (Bremer 2013). Within the present set of works (Bombana & Ariza, 2018; Bombna & Ariza, 2019; plus this study), it was addressed through the application of EPA logic. In the construction of the DL-BQI, the ICZM was conceptualized as its integrative building element (Bombana & Ariza, 2019). Moreover, reaching the overarching objective of this DL-BQI – to transparently capture the state of different beach processes – together with the identification of relations between the results of sub-indexes could aid for a systemic view of the Catalan coast (Sardá, et al., 2015), which was advocated by the narrative in question.

4.3. The general panorama of the Catalan coast

The set of stages settled by the DL-BQI process and followed by the present and previous works (Bombana & Ariza, 2018; Bombana & Ariza, 2019) were shown to be one of the possible ways of integrating a new paradigm inside the beach management field, given that “narratives are more robust than models” and, moreover, are responsible for giving context to such models (Allen & Giampietro, 2006). As beaches are becoming systems (Prigorine, 1983; WSSD, 2002) where processes and assets change and are subject to constant change, the models and narratives translating these systems have the duty and the potential to emphasize the embedded changes and, thus, adjust the context of management accordingly. Here, some assets and processes may be enhanced and, later, could affect narratives and subsequent models, improving their quality (Allen, et al., 2017). To cite an instance, hard engineering works that, until a few decades ago were thought to be a solution to control coastal erosion (a sort of beach change) by part of the science community and other institutions (a past narrative), have been shown to be (through observing the system), in the majority of cases, inefficient. So much so that, nowadays, there is a general agreement on the use of, when needed, other “softer” interventions instead of the former, such as beach nourishment and building of dunes (a new narrative originated from the observations).

As mentioned at the beginning of the present work, the highlighting of the chosen relevant assets and processes of a system is done through an encoding process of related information within a model (in this case, the building of the DL-BQI) which, after the application of the model (i.e. observation of the assets and processes; herein, the DL-BQI), conforms a message that can be translated to a comprehensive language by a decoding process (Rosen, 1993; Giampietro, et al., 2006). The characteristics of what was observed when put in context to the objectives of the model may shed light on potential conflict of interests. This is the main contribution of the present article and, therefore, the major implications of past and contemporary policies in the Catalan coast and the conflicts of interests found are expatiated in the following:

- Except for the EG narratives, all the others (SD, EP, ICZM), to a greater or lesser extent, have emphasized that the management of beaches developed in Catalonia in the last decades have been obviating the natural character of these systems by primarily promoting infrastructure, aesthetic quality and services and facilities for the development of tourism and leisure. That is, beach management has been widely guided by the precepts of EG. Except for particular locations or beach groups, the results of the DL-BQI outcomes have largely shown the consequences of the former. In general, the critical issues of this territory turned out to be high overcrowding, bad current conditions of dune systems, bad to average quality of surrounding area and the potential depletion of natural heritage. Partly explaining these processes, wide accessibility to beaches was also highlighted as a usual concern by the participants of the MS-meeting. Hence, we may say that there is a clear obsolescence of the EG narrative in proposing alternatives to complex coastal problems at the present context. The demands originating from worldwide acknowledgment of the sea-and-sand touristic potential of the Catalan coast showed to be conflictive with the maintenance of coastal assets and process for this and next generations. To emphasize and integrate the value of beaches as natural systems, as widely advocated by the EP narrative, may constitute a plausible alternative.

- The application of an integrative model – the DL-BQI – in the regional scale showed to have potential to aid for guiding action of beach management settled for the whole Catalan coast. To cite an instance, bad results of changes in physical processes and protection in only a few number of beaches contrasted with the conventional discourse in the media (Martinez, 2018; Madridejos, 2015; Mas, 2010), emphasizing an overall lack of protection capacity of Catalan beaches. We are not stating that conflicts highlighted by the media are nonexistent, but that they might be limited to few parts of the territory (e.g. the S’abanell beach) and that other conflicts are more urgent or explicative than the ones mentioned. Instead of focusing in proposing solutions for a territorial lack of protection (usually, beach nourishment), priorities for the whole Catalan panorama could firstly range around slowing down the artificialization of the surrounding area, restoring dune systems, restricting access through parking management (in the case of natural beaches), etc. Some of the later actions are acknowledged to be good strategies for enhancing the capacity of beaches as buffer zones to the energy that comes from sea (Garcia-Lozano & Pintó, 2018).

- Some discrepancies about management priorities between supporters of narratives other than the EG and beach users can be approximated. For example, despite the average good scores for waste and sewage management related to beach cleaning for recreational activities of the EG in this work and others (Ariza, et al., 2010), it was seen that beach users would prioritize (more) sand and sea cleanliness (Roca & Villares, 2008). Depending on the type of action taken in this sense, negative impacts on beach assets may occur (Defeo, et al., 2009), which are denounced by SD and EP. Overcrowding that was observed in an important part of beaches (especially urban and semi-urban) has been showed not to be the main concern of beach users (Roca & Villares, 2008), regardless of the fact that differences in this perception may vary within different groups of beach users (e.g. foreign visitors vs. Catalan residents) (Roca, et al., 2009). This underlined the need for awareness campaigns (McFadden, 2008) advocated by the SD narrative and which help to emphasize that the incorporation of only academic and beach users' perceptions in the process of building beach management indexes does not cater to the complexity of views associated with these systems. This not only justifies the need for beach management, but also highlights the importance of the integration of a multiple set of narratives.

- The diversity of Catalan beaches has been highlighted in the present and other studies (Breton, et al., 1996; CIIRC, 2010) and should be considered by coastal managers. Part of this diversity unfolded in the significant differences of DL-BQI results between beach types and geographical locations. As to what concerns management actions, this observation is important for catering to different objectives accordingly (Roca & Villares, 2008; Lozoya, et al., 2014; Dadon, 2018; McLachlan, et al., 2013). Major difficulties would possibly be seen when establishing intermediate objectives between the two extremes of EG (aims at satisfying beach users) and EP (aims at protecting ecological assets/processes and natural heritage), such as in semi-urban beaches (Bombana & Ariza, 2019). Possibly indicating this ambiguity, this last type indeed presented the worst average scores compared to the other two types (natural and urban) in 5 of the 8 sub-indexes of the dimension of recreational activity (i.e. microbiological quality of water, beach crowding, services and facilities, conflictual activities and comfort quality). We believe that local stakeholders, together with the regional and national ones could shed light on the main objective to be pursued.

- Both for the building of indexes and for their further potential use in policy, it is important to mention that objectives are not a static concept but evolve in time. An example regarding the DL-BQI model was that, even if leisure and touristic activities were promoted in urban beaches (as seen in the sub-indexes of the recreational activity dimension), MS-meeting participants expressed a call for integrating "renaturalization" efforts carried by some institutions, e.g. some municipalities of the Metropolitan Area of Barcelona, due to their potential for reestablishing some natural processes of beaches (the view of urban beaches may be moving from recreational spaces to natural systems) (Breton, et al., 2000). This call was emphasized in the suggested advancements of the natural heritage sub-index (Table 14). As for the policy actions, the bad scores for accessibility to natural beaches put into light a generalized ease of car access to these types of systems. which most stakeholders valued as critical. Strategies along this line were suggested, e.g. to create mechanisms to discourage a part of beach visitors (e.g. limit attendance) or to not promote access infrastructure. The aforesaid suggestions for accessibility, nonetheless, collide with other arguments, such as guaranteeing free access to a democratic space and easing access for disabled people.

Ultimately, we should highlight that it is not only beaches that can be defined as complex systems embedded in a connection between sub and upper systems but, in addition, the institutions intervening in the beach management field (e.g. State and Catalan government, municipalities, universities and research institutions, private sector, organized civil society, etc.) can be seen as a complex conjunct of systems interacting with each other (Argyris, 1982). DL processes of learning, hence, may be very useful for capturing the constantly evolving interrelations between them, while recognizing the effort endured in past situations by institutions regarding the understanding and management of beach systems. For instance, we cannot assert that the discrepancies found between this work and the knowledge acquired in former studies indicated that the latter were wrong, only that they have not been adequately updated to reflect the present challenges regarding beach management; however, they still contributed to the enhanced quality of information presented here.

5. CONCLUSIONS

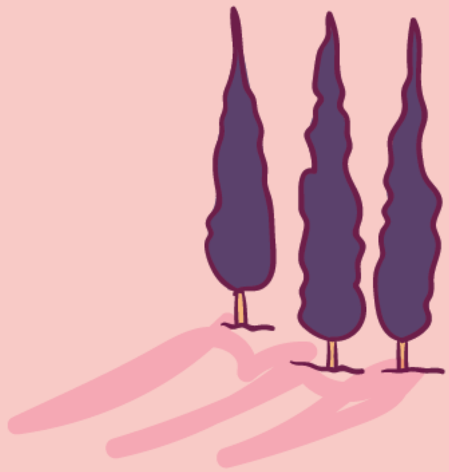
All of the factors implied in a framework for beach management – beach systems and surroundings, stakeholders and management institutions, accumulated information regarding the former and corresponding tools, defined objectives, etc. – are subject to constant changes, so that DL processes of learning are essential for adjusting and integrating the embedded values, logics and issues accordingly. Improving the knowledge quality for current challenges calls for multiple substantive, contextual and procedural processes that are capable of expanding perceptions about what and how we are observing such systems, the context in which we are doing it and the resulting uncertainties.

The use and test of a methodology for updating a tool according to constant changes, different dimensions and context are major contributions to the complexity science directed toward beaches, coupled with adaptive cycles advocated by this field. Also, linking the regional assessment with narratives has widened the overall comprehension of Catalan beaches and, thus, tackled uncertainties mainly related to different coastal epistemologies in the sphere of science for policy. This has proven to verify the utility of the expanded peer assessment, advocated by the PNS, in a relatively large territory.

In the present work, we double checked the capacity of DL-BQI model and outcomes on representing the reality of the Catalan coast, and the main perspectives and purposes of the stakeholders expressed by four main narratives (EG, SD, EP and ICZM). In general, the model was widely appreciated as being adjusted to its main objective of capturing the state of different beach processes in a transparent way, which was enabled by the EPA, and also as a tool producing valuable outcomes in the science-policy interface. Few updates of the DL-BQI and subsequent outcomes, however, were incorporated and introduced herein. From this exercise, we established and presented the general assessment of Catalan beaches by applying 14 of the DL-BQI sub-indexes for 96 beaches and drawing on some of the current implications and conflicts in this territory.

Catalan beaches have been mainly conditioned to supply infrastructure, aesthetic quality, services and facilities for the development of touristic and leisure activities, except in punctual cases and, in a more general way, for natural beaches. This has led to different pressures (e.g. cleaning, coastal development and engineering works, etc.) that are negatively impacting some of the ecological assets and natural heritage of beaches, such as landscape and coastal dune systems. Traditional economic growth linked to mass tourism and leisure has, thus, shown itself to be obsolete in the present context, and therefore, alternative models should be pursued. We were able to appreciate valuable natural heritage, which is not depleted in all areas, and where it is still possible to revert to certain harmful dynamics. A plausible alternative to the problems identified could potentially be the emphasis on the value of beaches as natural systems, as is widely advocated by the EP narrative.

The application of this study to a representative part of Catalonia supported the identification of management priorities, conflicting cases and biases embedded in past assessments. It also put emphasis on the diversity of the Catalan coast, which should be integrated by local, regional and national stakeholders who influence and who are being influenced by this territory. In this context, we recall that the traditional process of sustainability index building by experts and users has been demonstrated to not be useful for catering to the complexity of beach systems. An analysis of such panorama based on the aforementioned narratives justified the need for a more integrative beach management model in which different institutions, identified narratives, beach types and local particularities are placed on the table.



3. DISCUSSIONS AND CLOSING REMARKS

1. INTRODUCTION

In this section, I recall and relate the **major findings of the process of co-building indexes of beach management on the Catalan coast** (i.e. the DL-BQI), framed in a context of complexity and Post-normal Science (PNS) as a strategy to approach the complexity (Funtowicz & Ravetz, 1993). Besides providing **an overview of the global outcomes**, I also present **a general evaluation of the results** obtained from the phases of the double-loop (DL) process of learning (Figure 19). It is noteworthy that I developed these outcomes within a favourable context: Catalan beaches are relatively well studied sites by a multidisciplinary team of experts (e.g. Ariza, et al., 2008a; Breton, et al., 2000; Pintó, et al., 2014; Garcia-Lozano & Pintó, 2018). There is a body of institutions involved in their management, although the existing integration among them is still elementary (Ariza, et al., 2016), and a former tool for their analysis had already been proposed (Ariza, et al., 2010), that is, the SL-BQI. As mentioned in other sections, this former tool, anchored in a sound knowledge base built by multidisciplinary scientific experts, constituted the foundation for the study presented in this thesis, throughout which I intended to expand and enhance its embedded quality.

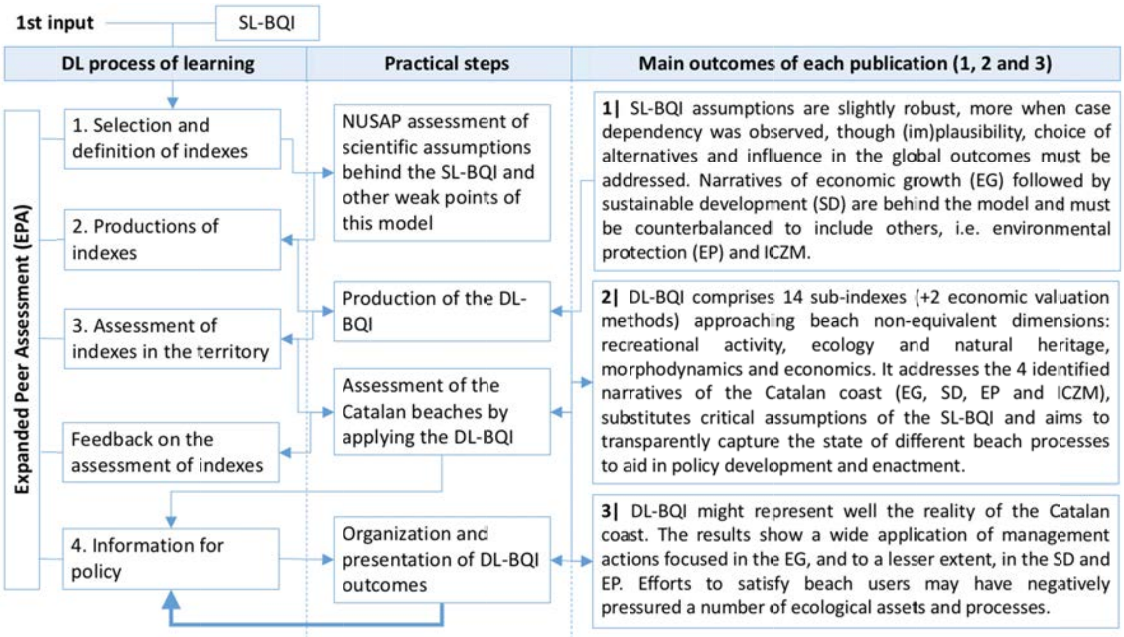


Figure 19. Main outcomes of each of the phases of the DL process of learning, organized by the publications presented in this thesis (Chapter 2). Source: Own elaboration.

In the **three publications composing this thesis**, it is possible to observe a **centrality of the expanded peer assessment (EPA)** (as the practical process of co-production), that is, the set of two multi-stakeholder meetings (MS-meetings), 5 focus groups (FGs) and complementary interviews and other informal sources, on acknowledging and working with the narratives that are capable of critiquing the knowledge available. In particular, this was done through the identification of assumptions, contributing to enhancing and highlighting shortcomings. From that, the potential of the EPA to create quality information about complex problems for policy is also acknowledged (Ravetz & Funtowicz, n.d.). In the next section, thus, I first delve into the **knowledge quality assessment** in the context of complex systems, particularly the Catalan beach systems.

Subsequently, I discuss **the PNS framework for the integrated coastal zone management (ICZM)** with a focus on the assessment of the Catalan beaches, developed in this research. **Methodological reflections and contributions** follow this discussion. Finally, I draw on **future research lines** in the science-policy interface for coastal management with a special focus on Catalonia.

2. KNOWLEDGE QUALITY ASSESSMENT IN THE CONTEXT OF COMPLEX SYSTEMS

The present study – which seeks to increase the knowledge (and its quality) available for Catalan beach systems by co-producing and, subsequently, applying a tool for their assessment – was mainly **motived by their condition as complex and developing systems** (Prigorine, 1983; Vallega, 1999; Botero, 2013; WSSD, 2002), to which the scientific field has being proposing best practices in only a limited way. For example, in the management of beach erosion through the development of coastal engineering works (hard or soft, e.g. respectively, building of groins or replenishment of sand), it is possible to observe different types of non-reported uncertainties, some of them non-reducible. That is, methodological uncertainties – in which likely probabilities cannot be delivered by the estimations of beach behaviour and of the design and consequences of the engineering works – were detected. These may be related to the lack of calibration of mathematical models (developed for other territorial contexts) calculating beach behaviour and designing engineering works. Also, limited inputs of past responses of such works (often poorly analysed), and the poor integration of potential impacts of storms on these works and the beach (usually relativized), can be observed (Funtowicz & Ravetz, 1990; Kovacic, 2015; Thieler, et al., 2000; Pilkey & Clayton, 1987). The indeterminacy and ignorance of certain inputs and outcomes on the endeavour of framing and representing the system, as well as the deficiency of the evaluation of the scientific assumptions integrating the mathematical models used, may be linked to an incomplete inclusion of viewpoints regarding the matter and the condition of beaches as developing systems. The former has accounted for ontological and epistemological uncertainties (Funtowicz & Ravetz, 1990; Kovacic, 2015; Thieler, et al., 2000; Pilkey & Clayton, 1987).

In the development of the chapters, **the focus on quality of knowledge referred to both a process and a fundamental concept**, which can be achieved (by knowledge products) throughout the "awareness of research context, explicitness and clear justification of the adequacy of the research properties with respect to the research objectives and appreciation for the interpretative context within which the research results would be applied" (Dell'Angelo, 2013, p. 26). In this sense, **with the processes of knowledge acquisition being enhanced – i.e. in a co-production of indexes – the content of the knowledge was consequently improved**, specially through the incorporation of expanded peers' viewpoints (e.g., the natural heritage of beaches comprise more than dune systems and landscapes, in contrast to what was displayed by the SL-BQI) or new scientific advancements (e.g., the analysis of dunes was updated to include the assets and processes observed by Pintó et al. (2014)). Additionally, **adjustments of the knowledge produced in respect to its context were particularly operationalized by the highlighting of assumptions and values behind the SL-BQI**, **the corresponding update into a DL-BQI and the observed management actions**

undertaken in Catalonia. The narratives identified were the main contributors to the foundation of this context (Maxim & Van der Sluijs, 2011).

To accomplish what I proposed in this thesis, **the relation of this model to that of Rosen** (Rosen, 1993; Giampietro, et al., 2006) **proved to be a useful theoretical insight**, given that it provided the scheme that serves as a background to the scientific modelling of complex systems. It depends on the **perception of an observed system** (e.g. the Catalan beaches), from which relevant attributes are determined and formalized (encoded) into a **formal system** (e.g. the DL-BQI), and the application of the formal system enables inferences between the links ruling the composing attributes, allowing **predictions to be made** (decoding) to assess, interpret and inform about the state of the system in question (e.g. the representation of Catalan beaches). In practice, the first MS-meeting, together with previous studies, and the critical assessment of the SL-BQI, helped to develop an expanded perception of the Catalan beaches (why to observe). The analyses of the former served as an input to (re)select analytical attributes (what to observe within a set of numerous assets and processes) and comprise them into the DL-BQI, adjusted to the context of the Catalan coast. Subsequently, the DL-BQI was applied to representative beaches of this coast (how to observe), supporting the evaluation of the attributes and interrelations, and the interpretation of these, in contrast with the narratives implied.

First, regarding the **framing of problems** and the representation of the Catalan beach systems, the perception of the observed system co-built during the first MS-meeting pointed to **the *lack of a long-term and integrated beach strategy for a sustainable management of the Catalan coast***, which was agreed as the main problem of the Catalan coast. It also highlighted the **hegemony and focus of the current management in prioritizing aspects related to the Economic Growth (EG) narrative**, followed by the Sustainable Development (SD) narrative. **The NUSAP assessment of the SL-BQI showed that this tool was somewhat in agreement with the aforementioned prioritization**, given that it was not designed to include the diversity of narratives other than the EG and, in a few particular sub-indexes, the SD (as shown in Figure 14 of publication 2). That is, **the pre-analytical choices of the SL-BQI were poorly capturing the existing complexity**, crucial for adequately representing the system, if the sustainability of Catalan beaches was to be considered the purpose of management, as well as if the transdisciplinary and democratic approach to these beaches was to be prioritized.

The mapping of narratives, therefore, aided in changing the pre-analytical choices and the subsequent step of encoding in a DL-BQI. This action drove the display of partial objectives for each sub-index to cater a wider number (and more detailed account) of different beach assets and processes. For example, at the sub-index level (3^{rd} level in Figure 4), the natural heritage sub-index was added to produce information about natural/cultural heritage to be conserved for the maintenance of the ability of beaches to sustain its ecological processes (Manderson, 2006). Most of the changes, however, were introduced at the level of variables and attributes (4^{th} level in Figure 4). To cite some instances, the variables of microbiological water quality; conditions of dune systems (former natural condition sub-index); beach safety; the state of water bodies (former water-sand pollution sub-index); changes in physical processes (former physical quality sub-index); and protection sub-indexes were all substituted. Those sub-indexes that included different scores for the valuation of variables of urban and semi-urban beaches (i.e. beach crowding, services and facilities, and accessibility) now also include a type of scoring adapted to natural beaches. Differences in the scoring of the slope of dry area of the comfort sub-index according to the geomorphological type of coast (i.e. abrupt, low, and deltaic coasts) were introduced, and the same was introduced to the scores of beach safety variables, only that in that case, they were conditioned to the level of risk. Adversely, the variables of the waste and sewage pollution sub-index are no longer scored differently depending on the beach type. Inclusions, suppression, or update of variables were generally observed (e.g. variables for the promotion of types of beach access other than cars).

In this context, **the DL-BQI was designed to produce representation outcomes capable of informing whether the objective(s) of management settled by the expanded peer community were being accomplished** (Figure 13 and Table 11). That is, in the DL-BQI, beach assets and processes valued by the different identified narratives were extended, adapted, and/or included, reflecting the fundamental and partial objectives of these narratives within, respectively, the sub-indexes and variables (Shields, et al., 2002). Thus, when **the DL-BQI was assessed *in situ***, it shed light on the directions that have been followed by the management actions so far, in particular, **enabling a comparison to the narratives explaining the current panorama of Catalan beaches**. For instance, it was by doing so that I could assert that some actions occurring in specific beaches or groups of beaches were starting consider environmental protection above economic growth (e.g. the DL-BQI services and facilities sub-index, by observing the suggestions of the environmental protection initially, was adapted to include natural beaches and, largely, to not well score the supply of services and facilities in this group of beaches; the result was that the almost general good performance for this sub-index and type of beach denoted an effort towards what has been advocated by the narrative mentioned). The application of the decoding step in Rosen's cycle (Rosen, 1993) during the DL-BQI process showed the discordance between the state of the Catalan beaches and some of the expanded objectives of EP, SD, and ICZM, that is, the ecological health (Karr, 1996) of beach systems is compromised, as associated landscapes and habitats have been significantly degraded.

The inclusion of narratives and objectives representing communities beyond academia derived from the adjustment of the model (SL-BQI into DL-BQI). The process showed the importance of **understanding science as one more actor among the set of beach epistemologies, and underlining and placing uncertainty on the centre of analysis** (Funtowicz & Ravetz, 1993). That is, the best information for understanding complexity has not come only by developing more studies from a specific epistemological position, but from the expansion of the epistemologies explaining the system under examination (Maxim & Van der Sluijs, 2011). For instance, in comparison to the SL-BQI, the DL-BQI only included one new sub-index (i.e. the natural heritage sub-index) that quantitatively would not indicate substantial scientific progress in the general set. However, the highlight of sub-indexes adjustments based on the EPA and, above all, the reporting on the influence of narratives, both in the model and in the outcomes, resulted in a remarkable increase in pertinence and usefulness (Kovacic, 2015).

In this way, **the precepts of quality in which the formal analysis of the Catalan beach systems advanced on were mostly pertinence and usefulness**, related to a reflexive analysis (by applying the set of methods used here) on the pre-analytical and analytical choices made (Kovacic, 2015). In terms of pertinence, the representation made by the DL-BQI and its application (assessment) in a representative part of the Catalan coast tried to answer to the problem as framed during this thesis. That is, it aimed to provide a tool capable of advising for the aforesaid *lack of a long-term and integrated beach model for a sustainable management of Catalan beaches*, by underlining the main processes and assets impacted by that, and by tracking the narratives behind such impacts (on the regional scale). As concerns usefulness, partial objectives settled by narratives following the problem framing were transposed to the different dimensions comprising the DL-BQI (Figure 13 of publication 2). Consequently, the information delivered by the further assessment of the sub-indexes of this tool has provided insights regarding such objectives by illuminating the difficulties and obstacles that could inhibit the necessary processes.

From these developments, I may say, thus, that **the six quality points regarding uncertainty within the assessment of complex problems** (Petersen, et al., 2003) **were, in a greater to a less extent, approached**. These are better detailed below:

1. **Problem framing**: This is understood mainly as a matter of perception of the problem, so that this thesis focused in an EPA capable of expanding viewpoints to co-define goals, related attributed, and causalities (Garnåsjordet, et al., 2012). This EPA was transversal to the four steps of the DL processes[21] (Garnåsjordet, et al., 2012), supplying feedback and greatly contributing to setting up a transdisciplinary approach (Max-Neef, 2005; Nicolescu, 2002). Especially regarding the point of the uncertainty assessment, and following Rosen's modelling relation (Rosen, 1993; Giampietro, et al., 2006), the framing of problems beyond the techno-scientific sphere was **responsible for expanding the acknowledgement of pre-analytical choices regarding what, from a wide set of possibilities, would be relevant to be observed and represented into a formal structure**. The identified set of narratives, in particular, enabled the analysis of scientific assumptions behind the SL-BQI (publication 1). That is, it detected a general technocracy, lack of contextualization of scientific information, focus in the economic growth narrative (i.e. what was mainly being observed by the SL-BQI referred to this narrative), and the (im-)plausibility of some of the SL-BQI sub-indexes. The widened perception of the problems and the substitution of assumptions accordingly (publication 2) preceded the further representation of the Catalan beaches (observed system) into a formal system for their assessment (i.e. the DL-BQI), and the underline of the current role of narratives in the science-policy interface (publication 3).

[21] That is, the 1) selection and definition; 2) production of indices; 3) assessment of indices; and 4) information for policy development (Garnåsjordet, et al., 2012).

2. **Involvement of stakeholders**: The entire EPA set **totalled 119 participations**[22] (not including e-mail exchanges), directly or indirectly involved with beach systems processes, which were identified before and in the 1st MS-meeting. Participations referred to representatives of institutions of diverse nature (e.g. three levels of government, organized civil society for different subjects, consulting firms, research and teaching organizations, etc.), many of which were engaged in the whole process of co-production. EPA procedures were designed to **give room to the discussion of the perspectives and responsibilities of peers regarding the Catalan beaches**. The first MS-meeting contributed significantly to the problem framing, and established the foundation upon which to set the context in which the next expanded procedures should be carried out, in particular, enabling the approximation of the beach dimensions, narratives, and potential management objectives that have not been previously identified. Working from this point, I was able to design the FGs in which the critics of SL-BQI and its embedded assumptions, through the NUSAP method, allowed for the combination and mutual disagreements of the existing techno-scientific knowledge with a new mixed knowledge outside the academic sphere. The results led to the DL-BQI conformation, assessed in the 96 beaches, and double-reviewed in the second MS-meeting. This last expanded procedure underlined shortcomings and suggested further updates of the tool and the usual practice of beach management. In spite of this wide involvement of stakeholders throughout this research (all publications), participation processes presented characteristics of dialogue and concertation, but not of negotiation, given that the latter refers to sharing of power between stakeholders in the decision-making process regarding beach management (Pomeroy & Douvere, 2008).

3. **Visualization and Selection of indexes**: The processes carried out through the 5 FGs, using the outputs of the first MS-meeting as the organizing core, were designed **to discuss the former SL-BQI structure and content, and to quali-quantitatively evaluate its main assumptions** by the criteria of the NUSAP method (publication 1). While the assumptions exercise enabled the identification of weak points of the already existing SL-BQI sub-indexes, the debate on the way these sub-indexes were structured showed misfits between these and the new expanded objectives (from the narratives) and potential limitations of the assessment (e.g. lack of resources). This led to **the update of the aforesaid tool (consequently, of sub-indexes and variables),** that is, primarily, I joined the capacities to the (re)selection of sub-indexes (e.g. updated variables of the comfort sub-index), the consideration of alternative ones (e.g. new variables of changes in physical processes and protection sub-indexes), or the inclusion of a new sub-index (e.g. natural heritage) in order to better capture beach processes and assets according to the wider set of narratives (publication 2). Some shortcomings of the new DL-BQI could be also seen (e.g. it does not properly include specific environmental management procedures, such as the cycle of waste management). Designed to verify the capacity of DL-BQI results in aid of the science-policy interface, the second MS-meeting was the main approach used for the former. The call for future advancements regarding the selection of sub-indexes and the clarification of the

[22] I here recall that I use the term “participations” instead of “participants” because some participants attended two or more of the expanded peer review procedures.

potential support that the results of the model in question could garner amongst other scientists and society were particularly underlined (publication 3).

4. **Appraisal of knowledge base**: This study contributed to **recommending and testing methods for the enhancement of quality knowledge**, such as the DL process of learning in a general sense, the EPA supplying feedbacks to the co-production of indexes, the NUSAP method for the analysis of assumptions, and the practical application of a tool to the studied territory followed by the open assessment of its outcomes. Mainly, the focus on scientific assumptions showed the weaknesses behind the knowledge made available by the SL-BQI, which were related to the values of the analysts making the assumptions, the number of alternatives available to these assumptions, the disagreements among peers, and the influence of resource limitations, in some cases, leading to implausible knowledge and/or to impacts to the global outcomes of the study. Such exercises highlighted the technocratic approach of the knowledge behind this tool, as well as a detachment between what it claims to enable and what could really be put into practice, being mostly grounded in the economic growth focused on user satisfaction. The approached multiplicity of viewpoints about the Catalan beaches besides the techno-scientific sphere supported adjustments to the knowledge base according to a wider set of narratives and dimensions, and together with the former, it highlighted limitations and subsequent impacts in both the further knowledge acquired and the set of methods. The consultations conducted with the expanded peer reviewers helped to design recommendations about these limitations.

5. **Mapping and assessment of relevant uncertainties**: The assessment of scientific assumptions of the SL-BQI led me to identify and evaluate uncertainties of different types. In particular, **methodological and epistemological uncertainties** (Funtowicz & Ravetz, 1990; Kovacic, 2015) **were primarily addressed in the DL-BQI building process**, especially those of excessive simplification or detachment to the socio-political context (including narratives). Context can be here understood in terms of understanding territorial specificities, but also in terms of knowledge production. Regarding the former, I recall the example of changes in physical processes that used to consider changes in beach grain size as indicative of human activity affecting natural processes (partial objective of the sub-index in question); nonetheless, the observance that these changes could naturally occur when under the influence of freshwater outfalls transporting sediment of different sizes added to the substitution of former variables for the detection of soft engineering works undertaken at beaches. On the other hand, the context in which the knowledge production is set refers to socio-economic and political influences on selecting what we should observe and how (Maxim & Van der Sluijs, 2011). In this sense, sub-indexes and, subsequently, data for their assessment were conditioned to the narrative(s) behind the objective assigned. Mapping and assessing the DL-BQI uncertainties, the methods' shortcomings, their implications for policy, the relation to narratives, and the consequences of these shortcomings to the assessment were broadly addressed throughout this work. For instance, the approached set of narratives fostered the inclusion of other processes and assets into the analysis, restructured objectives according to different types of beaches, and avoided aggregation between different dimensions and matters of analysis

(publication 2). Finally, those uncertainties primarily related to the emergent complexity, indeterminacy, ignorance, and spontaneity (Dryzek, 1987; Funtowicz & Ravetz, 1990; Kovacic, 2015) of beaches as developing systems (Prigorine, 1983) were not mapped, nor were they assessed.

6. **Reporting of the uncertainty information**: Basic reporting questions – "whom, on behalf of whom, when, where" (Petersen, et al., 2003, p. 8) – represents the communication conducted and whether this is carried out in a clear way to the audience. In the present thesis, this was **addressed in a limited way, through academic writing and a limited amount of feedback to the expanded peer community**. Essentially, this consisted of the expositions of limitations of this study during the EPA instances, the reporting of what was debated in these instances through meetings' minutes, and informal communications with some of the peers. Future advice coming from the knowledge here acquired should advance more in this area, which I believe is the weakest. Amongst the guidance topics for uncertainty assessment and communication (Petersen, et al., 2003), the aforesaid reporting questions and a straight idea of the message(s) to be focused on should be developed through clear means and reshaped for the target audience (e.g. if the results of DL-BQI outcomes are to be reported to Catalan stakeholders, Catalan and/or Spanish should be the languages used). The relevant uncertainties and potential effects in the science-policy interface should also, therefore, be emphasized.

The underlined points refer to a check-list developed within the PNS framework, and the **most important consequences** of applying them (Landerretche, et al., 2017) throughout this study are listed below:

(i) **the capacity of identifying and tackling biases**, e.g. the preponderance of certain narratives in the management and the SL-BQI was highlighted, reported, and, to an important extent, addressed by the new DL-BQI;
(ii) **the increase in democratic legitimacy**, e.g. for the first time, the environmental protection narrative was incorporated by listening to the citizen platforms, federations of fisheries and other institutions of the social ambit, and the included set of narratives brought new viewpoints about problems traditionally discussed in the academic circle (such as the assessment of the capacity of beaches in providing coastal protection);
(iii) **an analysis beyond that which is simplified by single numbers**, e.g. linking in words the DL-BQI outcomes to the narratives; and,
(iv) **the highlighting of embedded ignorance and limitations**, e.g. shortcomings of the DL-BQI pointed out in a transdisciplinary approach, which should be treated in further updates.

Lastly, we must recall the shortcoming in the co-building and assessment process, stemming from the consistently limited inclusion of peers expanding the knowledge in question, which conditions the whole analysis because of their centrality in making pre-analytical choices and identifying processes and assets on which the entire assessment is based. This, nonetheless, is not exclusive to the present research, as the collective exercises about complex socioecological systems will always be embraced within a context of multiple scales and changing processes, and, consequently, changing epistemologies and values. In any case, **the fact that the number and type of peers was limited did not compromise the exercise**, given that those who were participating did help to broaden the identification and understanding of the main conditionings, trends, processes, assets, key stakeholders, problems, narratives, scientific assumptions, and ways to approach beach management in Catalonia through the DL-BQI (Poggiese, 1993; Funtowicz & Ravetz, 1993; Garnåsjordet, et al., 2012).

There are not a significant number of studies putting the **Post-normal Science (PNS)** framework into practice (Dankel, et al., 2017), especially in a relatively large territory, and therefore **the present thesis can be seen as a valid contribution to the field**. First, it showed that the expanded peer assessment and corresponding tools of analysis (e.g. the NUSAP method, the inclusion of the double-loop feedbacks, etc.) could be **applied to this territorial extension**, despite of limitations regarding, in particular, the level of implicativeness and detailing (e.g. on a municipal scale, the proximity to local problems and organizations may flow better). Given that the objective of this work was to co-produce indexes for the assessment of Catalan beaches, which are complex dynamic systems, the aforementioned set of exercises confirmed its capacity in fostering adjustments to better cater to the evolving elements and assets according to territorial specificities. Here, not only a multiplicity of "physical" specificities (classified within the dimensions) of the Catalan coast were integrated, but, primarily, it considered the multiplicity of narratives explaining the coast in question and the related objectives established by those living in this coastal territory. From the resulting expansion, **mainly methodological and epistemological developments were thus carried out**. The outcomes of this practice, more than being tailored by the identified narratives, highlighted the differences in the intensities with which they are being influenced by the latter in the management field. At the same time, the main existing rooms of improvement, common in the modelling of complexity, were underlined (when possible) and did not curb the analysis and the information available to inform policy, coupled with the urgency in decisions. Finally, the practical experience confirmed **the potential of the framework in question to advise policy-makers with higher quality and better contextualized information**. Future developments concerning science for policy-makers in the context of governance could address the capacity-building for change in the social order (Van der Molen, 2018), beyond the existing increase in the social and technical quality knowledge for decision-making (Kønig, et al., 2017).

3. PNS FRAMEWORK FOR INTEGRATED COASTAL ZONE MANAGEMENT (ICZM)

Knowledge quality in the ICZM, in spite of having been advocated since the first publications in the matter (e.g. Cicin-Sain & Knecht, 1998), has usually lacked a conceptually robust definition closely linked to a transdisciplinary epistemology. It has instead been mostly linked to reductionist, technocratic approaches, prioritizing prediction over adaptation to uncertainty and democratic inclusion (Bremer, 2011). Indeed, few scholars have widely captured the need for transdisciplinarity in the exercise of building and reporting knowledge about coastal zones (e.g. Botero, 2013; Vallega, 1999). As a consequence, its operationalization has been weak, and the tools and empirical experiences derived have not been used to reflect on its shortcomings. The same applies in the beach management field, as it has been traditionally framed as a pragmatic ICZM exercise to be applied on the local scale (Williams & Micallef, 2009), inheriting its weaknesses as well.

By putting quality as the main aim of science for policy in a context of complexity, **the PNS emerged as a potential approach to what have been advocating by ICZM (and beach management)** about scientific production, but it has usually been caught in a contradiction. On one side, there has been the centrality of science in reporting for management, and, on the other, participatory developments of scientific information (Bremer, 2011; Bremer & Glavovic, 2013b). The framework in question, which recognizes that science is limited in its ability to aid in the complexity of current issues, asserted that quality would come from a merging of such contradictions (e.g. by "expanded peer assessments"), in which science is displaced to a horizontal line with other interested peers who are involved in or affected by the management of coastal zones. This, coupled with the evolution of ICZM to co-adaptive coastal (beach) governance, in which policies should be designed and applied not only by governments (who rely on scientists to act as advisors), but also by the civil society and private sector, reiterates the need of democratization and enlargement of the science-policy interface throughout time. Insights about the inclusion and integration of new epistemologies, means for deliberative instances, inclusiveness, the orientation towards social learning, the legitimization of cyclic dynamics and long-term strategies, and, consequently, the quality of knowledge have been supplied by the PNS field (Bremer, 2013). In this thesis, **both the process used for mobilizing knowledge (i.e. the EPA) and the products resulting from this process – the DL-BQI as the enhanced SL-BQI, and the corresponding outcomes – were interpreted in the context of quality**. Given that the EPA has already been discussed in the section 2, in the following section, I briefly draw on the DL-BQI assessment of the Catalan coast as the major product of this exercise.

3.1. The assessment of the Catalan coast

The exercise of knowledge assessment supported the process of **updating the SL-BQI into the DL-BQI**. This tool was **designed and applied to a never before addressed scale of territory – the Catalan coast – by selecting and assessing 96 representative beach systems**. **The narrative of EG (pro-tourism and market initiatives) has been underlying most existing management actions and tools** (James, 2000; Ariza, et al., 2008a; Peña-Alonso, et al., 2018). This, in the sphere of Catalan epistemologies about beach systems, was shown to coexist with at least three additional narratives: sustainable development (SD), environmental protection (EP), and ICZM. **It was by integrating the latter narratives that I was able to underline some processes obviated by the SL-BQI** (e.g. natural conditions of beaches were previously mostly reduced to the state of dune systems) and to address them in conformation with an updated DL-BQI (e.g. a wider perspective of natural heritage, including the state of water bodies and natural heritage assets). By applying the former, I also provided information for policy to counterbalance the EG narrative prioritization. The scale and detail of the assessment, the whole of the Catalan coast, helped to support the understanding of conflicts identified during the first MS-meeting (e.g. urbanization and artificialization) and, subsequently, aided in the indication of management priorities, which lean more towards the reality of this territory.

In Catalonia, the demands expressed by the EG narrative in the development of beach tourism and leisure have been somewhat answered, evident in **the high scores of the DL-BQI sub-indexes related to the satisfaction of beach users** (e.g. microbiological quality of water, waste and sewage pollution, comfort, etc.), **and related to general beach overcrowding** (for urban and semi-urban beaches, at least). The conditioning of beaches for enhancing the aforesaid satisfaction and increasing users' attendance have often been **linked to negative impacts on the ecological health of beaches** (Defeo, et al., 2009), as observed in the low scores of the sub-indexes of the current conditions of dune systems, natural heritage, and, for urban and semi-urban beaches, in the quality of the surrounding area (primarily landscape). Our findings echoed those **pointing out the destruction of natural heritage of Catalan beaches**, such as landscape and dunes (e.g. Ariza, et al., 2016; Garcia-Lozano & Pintó, 2017).

Sustainability – as the main goal of beach management, in which "the needs of the present" should not compromise "the ability of future generations to meet their own needs" (Brundtland, 1987, p. 43) – **would most likely not be attained** if the aforementioned negative impacts generally remain and intensify along the Catalan coast. These negative impacts are mostly explained by the economic productivity targeting mass tourism and leisure. **Incongruences thus arise** around the fact that while sea and sand tourism is a nature-impact activity (e.g. low quality of surrounding area observed in the DL-BQI results), it is also widely nature-based (e.g. landscape as an attractor) (Dadon, 2018). As Boda states, "more people and a bigger economy mean more productive activity, more houses, more roads, and more use of water, minerals, and land from the natural environment" (Boda, 2018a, p. 20). Moreover, regarding the socioeconomic sphere of sustainability, it is usually assumed that tourism brings prosperity to the territories in which it is the economic base. Some evidence, however, such as touristification[23] (Del Romero, 2018), inequality in the distribution of economic benefits, and denigration of local culture (Archer et al. 2005), indicate important social and cultural conflicts. I illustrate here the case of *Lloret de Mar*, which is one of the most internationally known and attended beach destinations in Catalonia, occupying the fifth position in Spain in number of hotels beds, one of the record municipalities in Catalonia in the amount of tourist taxes received, and even displays a "client satisfaction survey" about the beach on its webpage (Ajuntament Lloret de Mar, n.d.). At the same time, it was identified as the municipality with the lowest income per capita of all Catalan municipalities with more than 5000 habitants, which has been partially attributed to precarious jobs related to short, touristic seasonal occupations, unemployment in the other periods of the year, and, consequently, low yearly wages (Rodríguez, 2019). In this context, **the almost exclusive consideration of the EG narrative to establish assessment tools and policy may be interpreted as a deficient approach for addressing the main problems underlined by the EPA**. **The remaining narratives of EP, SD, and ICZM have been drawing on other alternatives** – for example, to a greater or lesser extent, the management action focus on beaches as

[23] "A process, and the resulting state in a definite space, of relatively spontaneous, unplanned massive development of tourism, which leads to the transformation of this space into a tourism commodity itself" (Del Romero, 2018).

natural systems – which question the trust in the EG to maintain itself throughout time. The substitution of perspectives in order to expand consciousness and rediscover meaning has been defended by, for example, deep sustainability in terms of the reflexivity about a widespread belief system of "economism based in rational, objective-materialistic, anthropocentric and scientific perspectives" (Ikerd, et al., 2014).

The narrative-based approach demonstrated that most of the stakeholders defending EG are employed by the municipal and regional governments (Figure 11 of publication 2), and receive the direct requests of a part of beach users and touristic entrepreneurs. These stakeholders also need the revenues of tourism and leisure activities to put beach management actions, at least partly, into practice. Nonetheless, by looking at how stakeholders establish coalitions around the other narratives (Figure 11 of publication 2), it is noticeable that **the majority of them (e.g. academic experts related to natural resource management, civil societies representing given social groups, aquatic sports federations, polytechnic schools, etc.) defend other management alternatives that advocate for different Ecosystem Management approaches** (Grumbine, 1994)**, and move away from the vision of the beach as "another square of the town"** (Personal comment-a, 2017). Some of this debate has been already assimilated by the public administration (e.g. the Catalan government is now promoting a limited provision of services and facilities in natural beaches, and some municipalities are starting to reject traditional practices linked to the maximization of beach services for tourism and leisure (Redacció Diari Més Digital, 2019; Personal comment-b, 2017), such that the influence of other narratives is increasingly being observed in the management of particular locations or types of beaches. These findings may indicate that alternatives to EG are currently starting to play an important role in regional and local beach policy.

The observation that the EPA **triggered the incorporation of other narratives to the DL-BQI co-building process points to the need for a governance beyond governments and academic/research institutions**. In particular, such an incorporation would shed light on alternative solutions to current conflicts that could be considered by future policies. Including narratives beyond those espoused by academia and public administration has been showed to increase the knowledge base to deal with adaptive systems and to yield the interpretation of the systems under study to those living in these places (Bremer, 2017). At the same time, ICZM, within the logic of governance, may constitute a way to integrate the anthropic activities in socioecological systems within schemes developed to account for ecological health (Van der Molen, 2018) as advocated, to a greater or lesser extent, by the narratives of SD, EP, and ICZM.

My main contribution target managers can now be counted with the DL-BQI model, which is capable of providing them with information to address much of the conflicts identified. The establishment of governance arrangements are, however, beyond the scope of this thesis. Further discussions settled through deliberation could provide details on where and how beach management actions should be applied, and by whom. For example, deliberation in the scale of municipalities may decide on establishing differentiated actions according to beach type, increasing the permissiveness of touristic and leisure activities in semi-urban and urban environments, or to prioritize environmental protection and reduce recreational activities as much as possible. The DL-BQI outcomes have provided insights into these various arenas. It is noteworthy, however, that I am not proposing the use of the DL-BQI outcomes to inform users, given that in the beaches presenting good performances, they could contribute to boosting mass tourism.

4. METHODOLOGICAL REFLECTIONS AND CONTRIBUTIONS

The most important methodological reflection of this thesis draws on **the role of the double-loop process (DL) of learning in encouraging the co-production of the indexes for the assessment of the Catalan beaches**. In that regard, in the first publication, an initial part of the phase 1 of the DL process – the (re)selection and (re)definition of sub-indexes – was carried out by the expanded assessment of the previous knowledge base, that is, the analysis of the SL-BQI assumptions. This made clear some of the choices of the SL-BQI related to the relevant narrative(s) and the perception of the observed system that, in publication 2, were further extended and developed. In this publication, hence, the oft-mentioned phase of the DL process was continued and aided for the development of phase 2 – the (re)production of sub-indexes. The subsequent DL-BQI was designed and presented based on the explanations of a wider set of peers, an important part of which came from outside the academic field. Finally, phases 3 and 4 were approached in publication 3 (in process): the application of the DL-BQI in situ; the resulting evaluation of the state of the Catalan coast; and the assessment of the former steps and content; and the policy implications of the information of the latter. As mentioned throughout this thesis, **the revaluation of the values, beliefs, and objectives that characterizes the double-loop learning was developed through expanded feedbacks of the knowledge that was in the process of construction (i.e. the DL-BQI and its outcomes), and that which had already been made available before (i.e. by the SL-BQI)**. In this thesis, the aforesaid feedbacks were operationalized by the set of expanded peer assessment (EPA), primarily the two MS-meetings and the 5 FGs. These dynamics were responsible for the co-production because, throughout this process, the scientific knowledge was discussed horizontally within a wider set of knowledge claims (Jasanoff, 2004).

I believe, therefore, that **this thesis has contributed to the field of beach management**, within the framework of the PNS, with a novel and high theoretically and practically loaded **plurality of procedures** used:

(i) In the overarching realm, the aforesaid **pathway for a DL process of learning** centred on the feedbacks enabled by the EPA;
(ii) In the operationalization of the **co-production of the DL-BQI**, to which Rosen's modelling relation served as a theoretical base;
(iii) In the **critiques of scientific models** (mainly, the SL-BQI), primarily through the NUSAP method for the assessment of scientific values and uncertainties; and
(iv) In testing the **epistemological and pragmatic quality of the DL-BQI applied regionally**.

Primarily, the results have shown that *beaches* – as complex socioecological systems in which, amongst other characteristics, spatial and temporal variability and spontaneity (Dryzek, 1987) are defining features – **require adaptive production, assessment, and application of knowledge for policy actions**. This should include knowledge updates according to evolving properties, assets, and processes, of both the observed system (e.g. the beach) and also of the observers (i.e. the ones discussing this knowledge) (Argyris, 1982). DL processes of learning, to which expanded feedbacks are integrated, constitute a mechanism to do so. However, more than only evaluating past outcomes of management actions, these processes re-evaluate the embedded rules and beliefs and ponder whether to alter them and the corresponding policies (Nilsson & Meek, 2016). In the case of Catalonia, the DL process and related EPA showed that the technocratic approach and scientific reductionism of coastal and beach management, including erosion management (section 2 of chapter 1), were being generally performed by the tools developed so far, as well as by the management actions endured in this territory. The technocracy and a certain reductionism of SL-BQI were observed in particular because it was predominantly built in an academic environment though multidisciplinary, and generally, beach function is oriented to comply with users' satisfaction (which is related to economic growth). It was somewhat justified by the possible influence of the co-defined (in the first MS-meeting) lack of integration in the region (publication 2), as well as the culture of beach management research in applying simple linear, rational, and technocratic solutions to produce knowledge that, when considering external participants, is usually done through consultation (e.g. beach users' surveys) (Bremer, et al., 2015). Advancing in application of the DL-BQI in the territory showed that **beach management actions were also being affected by a limited vision about the narratives in play, also prioritizing user satisfaction** (James, 2000; Ariza, et al., 2008a), and it is still subject to consequences of decisions made in the past regarding its surroundings (e.g. the building of houses, urban roads and engineering works that are depleted, among other things, as well as coastal dunes and landscape) (Sanò, et al., 2011; Garcia-Lozano & Pintó, 2018; Martí, 2005). As we have demonstrated, **the DL-BQI emerged in a different context**, to which mainly the PNS field provided theoretical and practical insights, and the research was opened up to criticism by other peers in a semi-linear path (feedback was being included as long as the study was being developed, independently of the phase in which it encountered itself).

Insights proposed by the peer review assessment related primarily to the identification of the narratives, dimensions, and problems composing the Catalan panorama that have not been previously identified and acknowledged in this manner. The link between these and the indexes was also first approached in the course of this study – in particular, the link with narratives. Applying the analysis of scientific assumptions of the beach management tools (publication 1) allowed me to **highlight the main biases** (e.g. the predominant narrative of economic growth) and **understand some processes** of the Catalan beaches that would have otherwise remained misjudged (e.g. the natural value of beaches beyond dunes and landscape). Also, the NUSAP criteria were calculated and made explicit (i.e. the influence of resource limitations, (im)plausibility, choice space, agreement among peers, analyst's subjectivity, and influence on global outcomes), shedding light on the areas in which scientific inquiry can be valuable. **In the case of beach management indexes, the influence on global outcomes and (im)plausibility in particular were shown to be the weakest points**. It was by having a clear idea of the aforesaid biases and adjusted beach processes that I was able to develop the subsequent work (publications 2 and 3). That is, the scientific assumption analysis of the SL-BQI, together with a comparison of the structure of this tool to the aspirations of Catalan stakeholders, provided me with the critical background to design an updated tool – **the DL-BQI** – more attuned to such aspirations. It **now includes new and adapted objectives**, as well as new methodologies capable of observing attributes and processes of beaches that were co-defined or co-reiterated as relevant. At the same time, the methodological set applied here has been shown to be useful to integrate concepts of ease of use and to maximize costs in the restructuring of the sub-indexes. A good example in this sense is the DL-BQI protection sub-index, which aims at indicating the capacity of beaches for protection and evolved from the SL-BQI sub-index with the same name and aim. The former implied the need of mathematical models not calibrated in Catalonia and other morphodynamics studies for analysing beach protection capacity through the effective beach width, the storm reach and the minimum beach width. The latter considers the events harming coastal infrastructure, which are approximated by an analysis of the regional newspapers, although this procedure also includes embedded uncertainties (e.g. local newspapers were not included, which could potentially indicate unregistered damaging local events). **Particular methodological advancements were thus observed regarding the products built, that is, primarily, the updates of the sub-indexes and variables**. Such enhancements of quality could be adapted to other contexts as a new form of analysing beach assets for future management policies, which would be more considerate of today's challenges. **The application of the DL-BQI in the coastal zone of Catalonia supported the identification of territorial specificities** (e.g. significant differences between beach types and provinces) and highlighted the potential of this tool in advising on regional policy. Additionally, it showed to be feasible for application in a context of material, time, and personal resource constraints, especially because most of the data used for the entire assessment of Catalan beaches was already made available by the institutions involved.

Finally, regarding the **PNS field**, I here recall how the integrated methodologies – the external (beyond academic circles) and internal (interdisciplinary reviews by experts and other informal sources) expanded peer assessments in the sense proposed by Kønig and colleagues (2017) - which has been shown to be **useful to enrich the quality of knowledge of a tool (and outcomes) designed for the management of beaches on a regional scale**. Working from this framework, the consideration of the Rosen's modelling relation (Rosen, 1993; Giampietro, et al., 2006) shed light on the phases implied in the design of a model (here, the index or set of sub-indexes): perception of an observed system, its encoding and inference in a formal system, and final decoding to draw on predictions/analyses of the observed system. It provided a conceptual scheme that highlighted the potential subjectivities in scientific (pre-analytical and analytical) choices throughout all phases of modelling. PNS, complementarily, emphasized that in the analysis of complex systems and problems (here, the entire modelling of the Catalan beaches) where *facts are uncertain, values in dispute and stakes are high, and decisions are urgent* (Funtowicz & Ravetz, 1990; Ravetz &

Funtowicz, n.d.), science should not be seen as a unitary source, mainly because it displays values and interests, and can only contribute with biased solutions to such problems (Ravetz & Funtowicz, n.d.). In this study, the consideration of the points discussed above, without denying specialized competences and the scientific culture in this territory on the management of beaches, led to the main justification for conducting the co-production of indexes in the Catalan coast. Subsequently, this co-production operationalized the approach to the subjectivity of the knowledge available through the NUSAP method and scientific assumptions analysis, the incorporation of narratives of the expanded peers for the development of the new DL-BQI, its practical application to the territory, and the expanded final assessment of this tool and its outcomes. Instead of the pursuit of truth, it posed social learning as the centre of its analysis (Bremer, 2013). **This work can be seen as a trigger for testing a set of integrated methodologies for the beach management field (in Catalonia and elsewhere), and it is also one of the initial practical applications of the PNS in a large territory.** In terms of its main results, it provided better contextualized information for policy-makers, especially due to the acknowledgement of inevitable and irreducible epistemological uncertainties, and to alternative insights to the science-policy interface. That is, the capacity of the PNS framework in aiding for more open and quality procedures in science for policy was tested and reiterated, emerging as a new rule that should be considered by the traditional science for management processes of this territory and others. The discussion of the methodological reflections and contributions advanced the introduction of future research ideas.

5. FUTURE RESEARCH IN THE SCIENCE-POLICY INTERFACE

As aforementioned, the set of methods applied in this study proved to be valuable in co-producing a more useful and pertinent tool for the management of Catalan beaches – the DL-BQI – and its subsequent assessment, and the process itself pointed at the room for improvement. Despite such room for improvement, the urgency of decisions to solve contemporary coastal problems (Funtowicz & Ravetz, 1993) recalls the importance of properly making use of information for policy. Because beaches are complex socioecological systems, **shortcomings cannot be fully minimized, but they can be better contextualized and highlighted**. The identified improvements of the DL-BQI and the need for future loops of learning serve as evidence of the need for future research in the case of Catalonia. The proper rationale of the learning process highlighted **the need for adaptive cycles of knowledge production** in which feedback may be constantly integrated (Argyris, 1982), pairing effectively with the aspirations of the ICZM, beach management, and PNS frameworks (Bremer, 2013).

Particularly, in the case of the Catalonian coastal assessments, it would be important to **develop advancements in monitoring and, thus, identifying the evolution of measured assets and processes, in addition to the evolution of the level at which narratives are being considered by beach management actions** and, because of that, their enactment in the territory (Bontje, et al., 2019). Here, nevertheless, it must be kept in mind that if potential changes in the structure of sub-indexes – for example, changing the object and scale of measurement – are endured, we require clear reporting on such changes before comparing assessment results. For example, if the assessment of accessibility was carried out on a given beach twice, first through the SL-

BQI (reported by Ariza, et al. 2010) and, subsequently, through the DL-BQI, and these assessments led to the same score for the corresponding sub-index, this would not indicate a maintenance of the state of accessibility attributes through time on this beach. That is because the DL-BQI accessibility sub-index introduced changes in the structure of its attributes (e.g. it now complies with the reverse traffic pyramid, as shown in publication 2), making the reporting on these changes necessary. In this research in general, the reporting of information for policy (addressed mainly in the last phase of the DL process (Garnåsjordet, et al., 2012)) is already probably one of the less approached points of uncertainty management (Petersen, et al., 2003). Essentially, **the results of this research should be translated to a common language beyond academia**, aimed at those with responsibilities for maintaining the sustainability of Catalan beaches. The main concerns should be the DL-BQI structure and the resulting outcomes related to narratives, in particular, the most relevant uncertainties of the analyses and their consequences (Petersen, et al., 2003) if the science-policy sphere is to prevent risks and have a responsible attitude towards the complex problems of beaches (Benessia & de Marchi, 2017).

Future works approaching the set of methodological procedures applied (section 4 of this chapter) would possibly allow for the **enriching of comparisons**, and it could contribute to enhancing the quality of such procedures and, consequently, the quality of knowledge available for future policies. Since the impact of scientific assumptions on the models approaching socioecological systems (SES) is still understudied,[24] I believe, regardless of the capacity of such a study to shed light on values and uncertainties behind these models (publication 1), it is important to expand their practice. In the case of this research, for example, this has been shown to be useful to the identification and analysis of conceptually loaded biases and of case-dependency objectives and calculations (later, these were addressed for the production of an enhanced model, i.e. the DL-BQI).

The enhancements of the DL-BQI presented here are usually context-dependent – for example, this tool targeted the scale of Catalonia, so that its **application in other scales without proper criticism would lead to uncertainties beyond the methodological sphere**. The adequate transcalar approach for further developments of the tool in question indeed remains an unanswered question. If the DL-BQI were applied to the whole Spanish coastal zone (Atlantic and Mediterranean regions), shortcomings could take the form of methodological inconsistencies (e.g. the thresholds of the beach crowding sub-index would be wrongly based on studies for Mediterranean areas) and epistemological abstractions (e.g. different crucial assets and processes to be prioritized would be neglected without a proper consideration of the main narratives of other Spanish regions). I consider, however, that if further adaptations in other contexts and scales were addressed **throughout an EPA, an "updated DL-BQI" could potentially produce satisfactory results that aid in policy development**. That is, the index structure presented here could be used as a guide to beach studies elsewhere. **Practical limitations, such as political will and lack of**

[24] I have, however, analysed the influence of assumptions on the SL-BQI global outcomes in publication 1.

resources (for continuous production of institutionally or academically created necessary data), however, could restrain possible future updates, both in Catalonia and in other regions. For example, it would be interesting to continue the present study in the same territory, especially due to the identified areas for improvement of the DL-BQI and because of the continuing of the monitoring. Nevertheless, material resources for the development of measurements are currently limited to funding, both in the academic (e.g. lack of material and pay for personnel that could create future fieldwork and participatory research) and government spheres (e.g. to enhance some of the data used that were made available by governmental institutions, such as the analysis of the state of water bodies in the scale of beaches and the monitoring of the coastal habitats).

Further potential analyses and discussions of narratives are expressly necessary, given that they can provide a wider understanding of the perceptions and interests behind the scientific assessment, and also for the proper management of the systems being assessed. In other words, it is by the analysis of narratives that the pre-analytical and analytical choices of the scientific knowledge can be tracked and the transparency about objectives can be ensured. This is particularly meaningful in terms of developing public policy for two reasons: first, this is significant because highlights the people or collectives targeted by the science developed with the aim of advising public policy. Second, this is especially important in terms of those who are responsible for suggesting and developing public policy actions based on the scientific knowledge produced. Future developments in this sense would thus contribute to deepening the understanding of management actions behind the DL-BQI results and, subsequently, of coastal management in a broader sense. The narratives identified in this thesis were used to settle pre-analytical choices of the DL-BQI; however, it is not possible to affirm that they are the only ones existing in the Catalan context. Additionally, understanding the types of participation – that is, communication, information, consultation, dialogue, concertation, and negotiation (Pomeroy & Douvere, 2008) – and ascertaining why some narratives were dominant above others would shed light on potential negotiations and alternatives to beach management. **The analysis of the distribution of power**, through analysis of discourses (Bryman, 2012), **could improve our understanding of how and by whom the Catalan coast is being explained, of the level at which narratives unfold in the management actions, and of the evolution of the aforementioned types of participation**. For example, it could help in tackling the hegemony of EG and its negative impacts in the sense that new economies that do not assume growth as imperative, but support the well-being of society. At the level of the stakeholders contributing to the formulation of narratives, questioning who was integrated in this process, and why they were integrated, would support the future incorporation of forgotten or invisible stakeholders, as well as advancing insights for the analysis of power. Within the logics of a PNS, **the incorporation of stakeholders could increase the knowledge quality**, primarily because of a wider democratization of purposes. Moreover, in the process of building ICZM indicators, the information about “who is in” and “for what” has been often neglected (Mazé, et al., 2017), and should be addressed by future studies in this field.

Regarding the ICZM theoretical sphere, **the present research tackled the myth of a positivist illusion** in which scientific knowledge alone would bring better management actions (Billé, 2008), showing that the inclusion of expanded peers beyond academic institutions can enrich the production of knowledge in the science-policy interface. If the outcomes of this co-production process could successfully support the application of positive management solutions for Catalonian problems, then it would confirm the representativeness, capacity, trust, and commitment to learning via expanded peers, which is included here through the knowledge co-production process (Schuttenberg & Guth, 2015). However, **it remains to be seen how coastal managers will use the outcomes of the process and whether they will continue co-building the DL-BQI in the present context of power relations**. Mazé and colleagues (2017) highlight that even when instances of coordination defended by the ICZM and based on governance scholarship are put into practice, frequently, the cooperation between stakeholders and institutions is idealized, masking the power of expert knowledge to impose framings and analysis, satisfying particular interests. We urge policy-makers and scholars to acknowledge and reverse the trend of a depoliticized management in order to properly understand the existing power relationships and tackle social exclusion (Mazé, et al., 2017).

Lastly, in this study, the practical consideration of characteristics of complexity (impermanency, inter-scale processes, differentiated time lags, heterogeneousness, etc. (Liu, et al., 2007)) was important to producing more adapted tools and knowledge in such a complex context and, by doing so, I verified that this type of approach is possible to carry out empirically. Transdisciplinary capacity-building was developed throughout this research, but not without obstacles, at a regional scale. Current times require this type of approach to incorporate complexity framing throughout scientific inquiry as a whole. **Learning processes, either single or double loops** (Argyris, 1982; Garnåsjordet, et al., 2012)**, should also advance reflections about the concept of "learning to learn", which is defined as triple-loop dynamics** (Siebenhüner, 2002); and about which new research in the main subjects of this thesis should shed light (e.g. by discussing some of the theoretical-practical concepts of the body of knowledge in social learning). In the triple-loop process, the organization(s) in charge of the acquisition, assessment, and action on new knowledge consider these procedures in themselves (Nilsson & Meek, 2016). **I believe this can be a way for research institutions to address today's complexities.**

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APPENDICES

APPENDIX A. FIRST LIST OF ASSUMPTIONS EMBEDDED ON INDEXES' STRUCTURE

Assumptions		Level of analysis	Evaluation method	
All indexes (Cervantes & Espejel, 2008; Ariza, et al., 2010; Ariza, et al., 2012; Botero, et al., 2015; Lucrezi, et al., 2016; Todd & Bowa, 2016; Semeoshenkova, et al., 2017)				
1	The observation (and measurement) of the processes related to the recreational activities, the natural heritage and ecology, and the morphodynamics of beaches are sufficient for analysing the sustainability of these SES	1st and 2nd levels	- Review by the authors	
2*	Specific characteristics such as the type of sediment of the beach, the form of the beach, the degree of urbanization and the type of residence in its surroundings do not influence the processes of the beach SES	All levels	- Focus groups - Online questionnaire - Review by the authors	
3	Beach user satisfaction is the main objective of beach SES studies	1st and 2nd levels	- Review by the authors	
4	The different processes of the beach SES are commensurable	All levels	- Review by the authors	
5	The inherent uncertainties of beach SES are reducible by adapting their processes to the specificities of the territory in which they are deployed	All levels	- Review by the authors	
6	The indexes provide clear, simple information that can be applied in practice	All levels	- Review by the authors	
BQI (Ariza, et al., 2010; Ariza, et al., 2012)				**Corresponding to:**
7	The satisfactory recreational activity of beaches is constituted by good quality of bathing waters, proper intensity of use, aesthetic pollution free spaces, adequate supply of services (including safety), access and parking, avoidance of bothersome activities, and comfort maintenance	2nd and 3rd levels	- Recreational activity FG - Review by the authors	Sub-indexes of Microbiological water quality**, beach crowding, environmental quality, services and facilities, beach safety, activities, access and parking, and comfort quality
8	Overcrowding by beach users (i.e. proper intensity of use) is adequately estimated through the observation of the space available for each beach user, which varies depending on the degree of urbanization in the surrounding area	3rd and 4th levels	- Recreational activity FG - Review by the authors	Beach crowding sub-index

* Also identified and assessed as a BQI assumption

** We considered the sub-index's modification predicted in the BQI document (Ariza, et al., 2010), i.e. the new requirements established in EU Directive 2006/7/EC, incorporated by the Catalan Water Agency (ACA).

[Continuation of] List of Assumptions embedded on indexes' structure.

Assumptions		Level of analysis	Evaluation method	
BQI (Ariza, et al., 2010; Ariza, et al., 2012)				**Corresponding to:**
9	Beach users' perception of beach crowding does not vary according to individual opinions	3rd and 4th levels	- Recreational activity FG - Review by the authors	Beach crowding sub-index
10	The aesthetic perception of beaches is dependent on the visual and olfactory water quality and on the visual sand quality. Water quality is estimated by observing its color, transparency, solid human waste, plant waste, marine plant waste, foam, tar, odor, oil and jellyfish; while sand quality is estimated by beach user waste, human waste, plant waste, marine plant waste, tar and jellyfish.	3rd and 4th levels	- Recreational activity FG - Review by the authors	Environmental quality sub-index
11	A good quality of services and facilities is verified by the provision of public safety, showers and feet washers, parasols and hammocks, bins, facilities for children, restaurant/bars and stalls, facilities for handicapped people, telephone, information, sanitary facilities and sports facilities	3rd and 4th levels	- Recreational activity FG - Review by the authors	Services and facilities sub-index
12	Annoying activities that may be observed on beaches are sports practiced outside of designated areas, the presence of pets, fishing in bathing areas and sailing activities	3rd and 4th levels	- Recreational activity FG - Review by the authors	Activities sub-index
13	The structure of the access and parking sub-index embraces all types of accessibility needed by the beach population	3rd and 4th levels	- Recreational activity FG - Review by the authors	Access and parking sub-index
14	Beach user comfort is dependent on beach width and step, the slope of the dry area, the slope of the wet area, the presence of obstacles and abrasive material, water temperature and the % of sunny days	3rd and 4th levels	- Recreational activity FG - Review by the authors	Comfort quality sub-index
15	Beach safety for users is guaranteed by lifeguard services, transport material, communication material, rescue material, sanitary material, emergency warnings, buoys, signaling of dangerous areas and activities, risk assessment of each beach, preventive plans, accident indicators and the absence of wave regime risk	3rd and 4th levels	- Recreational activity FG - Review by the authors	Beach safety sub-index

[Continuation of] List of Assumptions embedded on indexes' structure.

Assumptions		Level of analysis	Evaluation method	
BQI (Ariza, et al., 2010; Ariza, et al., 2012)				**Corresponding to:**
16	The evaluation of the surrounding quality (hinterland artificialization in a 500m strip around the beach and in a strip of 200 m offshore from the emerged beach), of the state of natural conditions in the emerged beach part and the ecological, physicochemical and chemical state of the water masses provide an adequate measure for the management of ecology and the natural heritage of Catalan beaches	2nd and 3rd levels	- Ecology and natural heritage FG - Online questionnaire - Review by the authors	Sub-indexes of Quality of surrounding area, Natural conditions, Water-sand pollution*** and Microbiological water quality **
17	The quality of the beach surroundings is basically determined (negatively) by the urbanization of the hinterland, the artificialization of the visual basin and the existence and size of infrastructures on the emerging beach and the adjacent marine zone	3rd and 4th levels	- Ecology and natural heritage FG - Online questionnaire - Review by the authors	Quality of surrounding area sub-index
18	The monitoring of the state (and potential) of the dune system is adequate and sufficient to determine the natural heritage of the emerged part of Catalan beaches. This state (and potential) is determined by the numerical evaluation of the presence of typical dune system flora species in Catalonia, the extension of the dune vegetation area in relation to the wind controlled part of the beach and the visual assessment of the dimension of the habitat	3rd and 4th levels	- Ecology and natural heritage FG - Online questionnaire - Review by the authors	Natural conditions sub-index
19	A good indicator of the quality of a beach's aquatic system is composed of the biological, physicochemical and chemical quality. Biological quality is measured by observing the state of marine phanerogams, phytoplankton, macro algae and macro invertebrates, physicochemical quality by the general conditions of nutrients (for example, nitrate) and preferential substances (for example, selenium) and chemical state by the observation of priority substances and other pollutants (for example, pesticides and heavy metals)	3rd and 4th levels	- Ecology and natural heritage FG - Online questionnaire - Review by the authors	Sub-indexes of Microbiological water quality** and Water-sand pollution***
20	Beach morphodynamics should be assessed by analyzing beach capacity for coastal protection and human impacts on beach physical structure	2nd and 3rd levels	- Morphody na-mics FG - Review by the authors	Sub-indexes of Physical quality and Protection

** We considered the sub-index's modification predicted in the BQI document (Ariza, et al., 2010), i.e. the new requirements established in EU Directive 2006/7/EC, incorporated by the Catalan Water Agency (ACA); ***The same as the former, but regarding the requirements established in EU Directive 2000/60/EC, incorporated by the ACA.

[Continuation of] List of Assumptions embedded on indexes' structure.

Assumptions		Level of analysis	Evaluation method	
BQI (Ariza, et al., 2010; Ariza, et al., 2012)				**Correspon ding to:**
21	The effective width of the beach, the storm reach and the minimum width of the beach enable a good representation of the capacity of beaches for coastal protection. The use of the *SBeach* model is adequate to calculate beach protection capacity on Catalan beaches	3rd and 4th levels	- Morphodyna-mics FG - Review by the authors	Protection sub-index
22	The anthropogenic impacts on the physical quality of beaches can be identified by the changes in grain size, beach surface and wave regime	3rd and 4th levels	- Morphodyna-mics FG - Review by the authors	Physical quality sub-index
23	All values of beaches can be expressed in monetary terms	2nd and 3rd levels	- Beach economics FG - Review by the authors	Traditiona economic valuation methods, such as the travel cost method and the hedonic prices
24	The value of beaches, according to the Travel Cost Method, is deduced from how willing people are to visit them, which is estimated through information about the distance travelled, the transportation used, the number of people (in the transportation) and the opportunity cost	3rd and 4th levels	- Beach economics FG - Review by the authors	Travel cost method
25	The value of beaches is deduced from how willing users are to pay more for the accommodation that is close to these places, which is identified through decomposition of the total price of a hotel room or home	3rd and 4th levels	- Beach economics FG - Review by the authors	Hedonic Prices

APPENDIX B: DL-BQI SUB-INDEXES AND CORRESPONDING ATTRIBUTES

To avoid excessive repeating, this version of the DL-BQI correspond to the one developed in the framework of the third publication composing this thesis (chapter 2.3) in which updates from the DL-BQI first version[25] (Bombana & Ariza, 2019) are already included.

For most of the analyses deployed, sub-indexes consider three types of beach in accordance with their level of urban development (adapted from Ariza, et. al, 2008a):

- Urban beaches (UB): Usually found in the main town center, these and their surroundings are very densely developed (over 60% of urbanized hinterland is of high density), the related land use type being primarily urban. Generally, fixed seafront promenades are located in parallel to the beach.
- Semi-urban beaches (SUB): Relatively outside of the town center, these are surrounded by less dense urbanization (50% maximum of low density), corresponding to residential areas and presenting both natural and urbanized land use types.
- Natural beaches (NB): Also distant from the main town center, these are surrounded by very low density (30% maximum) or null urbanization.

On a regional scale like that of the Catalan coast, the further suggested frequencies of measurements might be adjusted according to future cases of deliberation regarding beach management and, especially, to the availability of resources.

B.1. Microbiological Water Quality Sub-Index

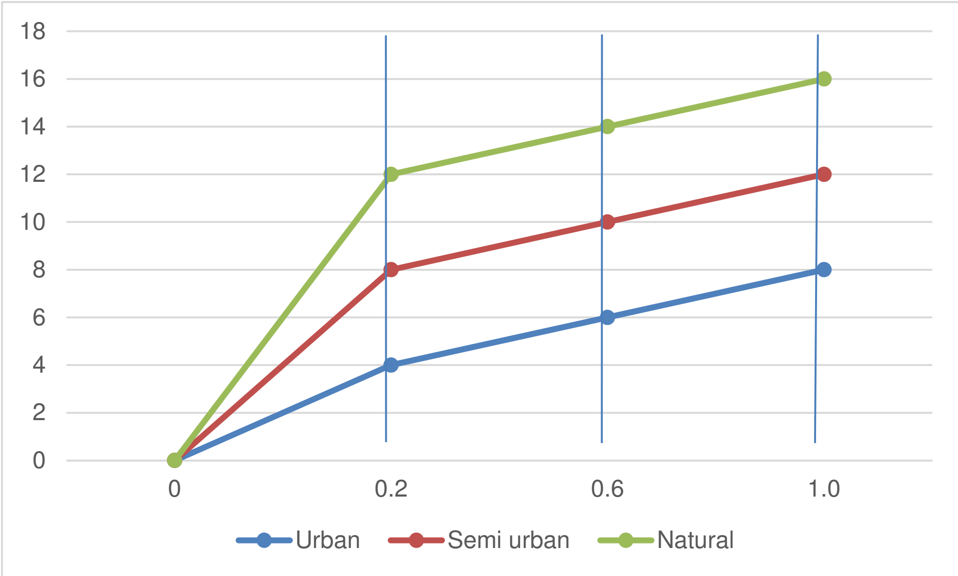
	Escherichia coli	***Enterococcus intestinals***	**Score**	**Short-term pollution episode**
Excellent	<= 250	<= 100	1	Each episode subtracts 0.1 from the score
Good	250 – 500	100 - 200	0.8	
Sufficient	250-500	100-185	0.5	
Insufficient	> 500	> 185	0	

Source of data: It was used the report of the annual assessment carried out by the Catalan Water Agency (ACA, 2016) taking into account the requirements established in Directive 2006/7/EC. Outputs of *Escherichia coli* and *Enterococcus intestinals* are expressed in CFU/100 ml.

B.2. Beach crowding Sub-Index

		Beach type[1]		
Classification[2]	**Score[3]**	**UB**	**SUB**	**NB**
Optimal	1	> 8 m^2/user	> 12 m^2/user	> 16 m^2/user
Good	0.6	4 >= x <= 8 m^2/user	8 >= x <= 12 m^2/user	12 >= x <= 16 m^2/user
Bad	0.2	< 4 m^2/user	< 8 m^2/user	< 12 m^2/user

[25] The original first version can be found in the appendix of Bombana & Ariza (2019) work.



[1]In further advancements, it should be verified the usefulness of assessing this classification in accordance with the type of use of the surroundings (e.g. touristic or residential) rather than urban development level.
[2]There are different methodologies to calculate crowding (Morgan, 2018) but, in my case, I counted beach users, hourly, by crossing the beach area with the data collected from photographs taken over the course of a whole day (sunlight hours) of the peak season in a representative sector of the beach, i.e. from mid-June to mid-September. The report on outcomes should be yearly.
[3]The stressed thresholds are defined according to past studies conducted for Mediterranean areas (MOP, 1970; PAP, 1997).

B.3. Waste and sewage pollution Sub-Index

Classification		**Good**	**Regular**	**Bad**
Score[1]		**1**	**0.5**	**0**
Water Quality	**Color**	Normal	-	Not normal
	Trans-parency	Normal	-	Not normal
	Solid human waste	None or little	Intermediate	High quantity
	Foam	If not present, neutral	-	If present, - 0.1
	Tar	If not present, neutral	-	If present, - 0.2
	Oil	If not present, neutral	-	If present, - 0.2
	Odor	If not present, neutral	-	If present, - 0.2
State of entrances	**General waste**	Clean	-	Dirty
Sand quality	**Solid human waste**	None or little	Intermediate	High quantity
	Tar	If not present, neutral	-	If present, - 0.2

[Continuation of] Waste & sewage pollution sub-index

Classification	Good	Regular	Bad
Score[1]	**1**	**0.5**	**0**
Rainwater outfall	If not present, neutral	-	If present, - 0.1
Short-term pollution episodes	If not present, neutral	-	If present, - 0.1
Beach closure due to pollution	If not present, neutral	-	If present, - 0.25

[1]Except for beach closure due to pollution and short-term pollution episodes (which can be assessed using the information supplied by ACA), this sub-index currently corresponds to a quali-quantitative observational assessment that should be carried out, primarily, during the peak season (in our case, from mid-June to mid-September) yearly. The overall average result is calculated by summing up the average score (normalized from 0 to 1) of the group of "usual" variables (i.e. water color, water transparency, water and sand solid waste, and state of entrances) with the extra (negative) scores, when present, of the remaining variables (i.e. water foam, water tar, water oil, water odor, sand tar, rainwater outfall, short-term pollution episodes, and beach closure due to pollution).

B.4. Conflictual activities Sub-Index

Forbidden activities[1]	
Pets	Subtracts 0.1 from the initial score of 1, unless permitted
Fishing during bathing hours	Subtracts 0.2 from the initial score of 1, unless permitted
Sailing activities in bathing areas	Subtracts 0.2 from the initial score of 1, except for areas specifically assigned for this
Peddlers	Subtracts 0.1 from the initial score of 1
Sports[2] outside specific areas	Subtracts 0.1 from the initial score of 1
Non-forbidden activities[1]	
Loud music / noise	Subtracts 0.1 from the initial score of 1
Other bothering situations	
Perception of robbery	Subtracts 0.1 from the initial score of 1

For this sub-index, all beach types are equally considered, therefore, no differentiation of classification is observed in this regard.
[1]In general, indicates the observational measurements carried out on beaches during high season, except for the perception of robbery that is obtained from the user survey (though, not carried out in this thesis). The frequency of the observation should be yearly.
[2]Refers to those permitted on the beach and reflected in the local plans for the season.

B.5. Services and facilities Sub-Index

Classification		Good			Regular			Bad		
Score[1]		1			0.5			0		
Beach type		UB	SUB	NB	UB	SUB	NB	UB	SUB	NB
Density of services and facilities		<35%	<20%	0%	35> x <50%	20> x <35%	0>x < 10%	>50%	>35%	>10%
Facilities	Showers and footbaths	Showers/ footbaths separated <150m	Only at entrances	Non-existent	Showers/ footbaths separated between 150 and 250m	More than just at entrances	-	Showers and footbaths separated >= 250m, or non-existent	Non-existent	If there are showers and footbaths
	Garbage cans	Separated <50m. With segregated waste disposal in all of them +0.1, whereas in some of them +0.05.	Garbage cans only at entrances. With segregated waste disposal in all of them +0.1, whereas in some of them +0.05.		Garbage cans separated by 50m to 100m. With segregated waste disposal in all of them +0.1, whereas in some of them +0.05.	-		Garbage cans separated >100m. With segregated waste disposal in all of them +0.1, whereas in some of them +0.05	More or less than in each entrance. If segregated waste disposal in all of them +0.1, whereas in some of them +0.05	
	Facilities for children	Existing	Non -existent		-			Non -existent	Existing	
	Sanitary facilities	Facilities separated by a maximum of 300m.	Only at the entrances	Non-existent.	Facilities between 300 and 500m.	More than just at entrances.	-	Facilities separated by more than 500m or none.	None.	Existing.
	Sports facilities	Existing.	-	Non-existent.	-			Non-existent.	-	Existing.

[1]In general, this corresponds to an observational quali-quantitative assessment that should be carried out, primarily, during high season (in our case, from mid-June to mid-September) yearly. The overall average outcome is calculated by the average of the normalized scores (in a range of 0 to 1) of three groups of variables: Density of services and facilities, Services, and Facilities. Potential extra points of the variables of garbage cans and information are added to overall average outcome.

[Continuation of] Services and facilities sub-index

Classification		Good			Regular			Bad		
Score[1]		1			0.5			0		
Beach type		UB	SUB	NB	UB	SUB	NB	UB	SUB	NB
Services	**Beach guarding**	Present			-			Absent		
	Parasols and hammocks	Closed parasols/ hammocks when not in use.	Non-existent		None.	Closed parasols/ hammocks when not in use.	-	Open parasols/hammocks.		If there are parasols/ hammocks.
	Bathing support areas for handicapped people[2]	1 per municipality with all the infrastructure and corresponding staff			None per municipality, but there are adapted entrances			None per municipality and without adapted entrances at the beach		
	Restaurants/bars and stalls	Seasonal facilities in the DPMT separated by at least 200m.	Seasonal facilities in the DPMT separated by at least 300m or none.	Non-existent.	Seasonal facilities in the DPMT, not separated by at least 200m.	Seasonal facilities in the DPMT, not separated by at least 300m.	-	Perma-nent facilities in the DPMT or none.	Perma-nent facilities in the DPMT.	Existing.
	Mobile signal or WI-FI	Medium to high mobile signal or an emergency call point			-			Low mobile signal / no emergency call point		
	Information	Existing at entrances and on the beach. If designed for disabled people, +0.1.		Only at entrances. If designed for disabled people, +0.1.	Only at entrances. If designed for disabled people, +0.1.		None.	Non-existent.		More than just at entrances. If designed for disabled people, +0.1.

[1]In general, this corresponds to an observational quali-quantitative assessment that should be carried out, primarily, during high season (in our case, from mid-June to mid-September) yearly. The overall average outcome is calculated by the average of the normalized scores (in a range of 0 to 1) of three groups of variables: Density of services and facilities, Services, and Facilities. Potential extra points of the variables of garbage cans and information are added to overall average outcome.

[2]This includes: 1) Support infrastructure on the submerged (e.g. floating wheelchair) and emerged part of beaches (footbridges connected with available services; adapted services such as showers, footbaths and sanitary facilities; signposting indicating the accessible services; and PA systems for handicapped people), and 2) Support staff during the hours of lifeguard service. Future advancements should incorporate new legislation by applying the Accessibility Act 13/2014 of the Catalan Parliament.

B.6. Accessibility Sub-Index

Classification		Good			Regular			Bad		
Score[1]		1			0.5			0		
Beach type		UB	SUB	NB	UB	SUB	NB	UB	SUB	NB
Surroun-dings	Signposting	Within 200m			More than 200m			None		
Car access	Parking	Existent		Nonexistent	-			Nonexistent	Existent	
	Parking fee	Nonexistent		Existent	-			Existent		Nonexistent
	Distance of parking from beach	>= 200m.	>= 300m or none.	>= 600m or none	100-200m.	100-300m.	200m-600m.	<= 100m or none.	<= 100m.	<= 200m.
	Distance of parking for disabled people	0-50m.		-	>= 50m.		-	Non-existent.		-
Bicycle access	Bicycle lane	Existing.	If existing, + 0.1.		-			Non-existent.	-	-
	Bicycle parking	Existing.	If existing, + 0.1.		-			Non-existent.	-	

[1]In general, this corresponds to an observational quali-quantitative assessment that should be carried out, primarily, during high season (in our case, from mid-June to mid-September) yearly. Future advancements should better incorporate new legislation by applying Accessibility Act 13/2014 of the Catalan Parliament. For instance, due to the use of wheelchairs by handicapped people, the minimum width of footbridges should be observed. The average final outcome is calculated by the average scores (normalized between 0 and 1) assigned to all variables in the case of UB. In the case of SUB, the same occurs except for the variables of bicycle access that account as extra scores to the average final result; whereas, in the case of NB, only the average of the variables of surroundings and car access summed up for the average final outcome (normalized between 0 and 1), to which the remaining variables (i.e. bicycle and pedestrian access, and public transportation access), when present, are added as extra points.

[Continuation of] Accessibility sub-index

Classification		Good			Regular			Bad		
Score[1]		**1**			**0.5**			**0**		
Beach type		**UB**	**SUB**	**NB**	**UB**	**SUB**	**NB**	**UB**	**SUB**	**NB**
Pedestrian access	**Pavement (walking)**	Easy and safe.		If good and safe at the entrances, +0.1.	Safe, but not easy; or, easy, but not safe.		-	Not safe, not easy.		-
	Distance between pedestrian entrances	<50m or existing seafront promenade	Single or having, at least, 100m of distance.	-	Between 50 – 100m.	Entrances separated by >=200m.	-	>=100m.	Existing seafront promenade	If existing seafront promenade, -0.1.
	Footbridges	Existing in all entrances and connected with services and facilities.	Just at main entrances.	If existing, +0.1.	Existing in all entrances, but not connected with services and facilities.	More than just at entrances.	-	None or less than in all entrances.	None.	-
Public transportation access	**Public transportation**	Existing.		If existing, +0.1.	-			Nonexistent.		-
	Public transportation for handicapped people	Adapted bus and stop.		-	Adapted bus.		-	Nonexistent.		-

[1]In general, this corresponds to an observational quali-quantitative assessment that should be carried out, primarily, during high season (in our case, from mid-June to mid-September) yearly. Future advancements should better incorporate new legislation by applying Accessibility Act 13/2014 of the Catalan Parliament. For instance, due to the use of wheelchairs by handicapped people, the minimum width of footbridges should be observed. The average final outcome is calculated by the average scores (normalized between 0 and 1) assigned to all variables in the case of UB. In the case of SUB, the same occurs except for the variables of bicycle access that account as extra scores to the average final result; whereas, in the case of NB, only the average of the variables of surroundings and car access summed up for the average final outcome (normalized between 0 and 1), to which the remaining variables (i.e. bicycle and pedestrian access, and public transportation access), when present, are added as extra points.

B.7. Comfort Quality Sub-Index

	Classification	Good		Moderate		Bad	
	Score[1]	1		0.5		0	
Physical	Width[2]	20-35m		15-20m or 35-50m		<15m and >=50m	
	Slope of dry area[2]	0-4º		4-6º		Above 6º	
	Slope of wet area[2]	Abrupt coasts	Low and deltaic coasts	Abrupt coasts	Low and deltaic coasts	Abrupt coasts	Low and deltaic coasts
		1-5º	0-5º	0-1º or 5-8º	5-8º	Above 8º	
	Obstacles[2]	No obstacles		Obstacles present in less than 15% of shoreline		Obstacles present in more than 15% of the shoreline	
	Step[2]	<10cm		Between 10 and 20cm		Step >= 20cm	
	Abrasive material[2]	Without or disperse abrasive material		Significant accumulation that does not obstruct entry to and exit from the water along 75% of the shoreline		Accumulation that obstructs entry to and exit from the water in more than 25% of the shoreline	
Jelly-fish	Presence of jellyfish[3]	From 0 (highest average percentage observed in Catalonia between 2007-2010) to 1 (lowest average percentage)					
Weather	Water temperature[4]	23-27º		21-23º or 27-29º		<21º or >=29º	
	% of rainy days[4]	From 0 (all days are rainy) to 1 (no rainy days)					
	% of cloudy days[4]	From 0 (all days are cloudy) to 1 (no cloudy days)					
	% of strong wind[4]	From 0 (all days presented strong winds) to 1 (no days of strong wind)					

[1]For this sub-index, all beach types are equally considered, therefore, no differentiation is observed in this regard, except for slope of wet area (abrupt X low and deltaic coasts). The final score is calculated by the sum of the average score found for each variable.

[2] Data needed to carry out this assessment may be obtained from *in situ* measurements taken during the summer season (in our case, from mid-June to mid-September) yearly.

[3] The assessment is based on the average frequency detected by the Catalan Water Agency (ACA) in the territory of Catalonia between the summer months of the 2007 – 2010 period. However, calculations should be made observing the annual summer season, in which an average of 70 inspections are usually carried out by the aforesaid organization.

[4] Although we used the study by Morgan, et al. (2000) to update these attributes, the outcomes of this assessment are expressed following the perceptions established for Catalonia through user surveys (Ariza, et al., 2010). The data needed for their calculation is available from the State Meteorological Agency (i.e. AEMET).

B.8. Beach safety Sub-Index

Variables[1]		Beach type according to a crowding criteria[2]		
		High risk ($<10m^2$ / user)	Medium risk ($10\text{-}60m^2$ / user)	Low risk ($>60m^2$ / user)
Human resources	Supervisor	1 / beach		-
	Lifeguard	1 / surveillance point		-
		1 / lifeboat		-
		1 for every 2 medical emergency points or, if there is only one point, 1 / medical emergency point		-

[Continuation of] Beach safety sub-index

Variables[1]		**Beach type according to a crowding criteria[2]**		
		High risk ($<10m^2$ / user)	**Medium risk ($10-60m^2$ / user)**	**Low risk ($>60m^2$ / user)**
Human resources	Recreational boat skipper	1 / lifeboat		-
	All personnel must be of legal age; be at least certified lifeguards for aquatic activities; be duly identified and uniformed; and have the minimum equipment: rescue flotation device, fins, mask and snorkel, portable first aid kit, binoculars and whistle.			
Surveillance point		1 / 400m	1/800m	-
	This must be at a height of at least 2.5m between the seat and the ground; located as close as possible to the entrances and walkways for handicapped people and at a distance of not more than 20m from the sea line; displaying a set of flags of a minimum height of 3m visible from anywhere on the beach and from the entrance points. The flags must be of a size of 1.5 x 1m.			
Medical emergency and first aid point		1 guaranteeing a response time of <4min	-	-
	This must be located in an easily accessible location, signposted and adapted to people with reduced mobility; have communication equipment, a direct telephone with 122 (emergency number) and PA system; have the minimum equipment: running drinking water, electricity supply, treatment room, treatment material, spineboard with positive buoyancy, rigid stretcher, immobilization devices, cervical collars and braces for all sizes, a complete oxygen therapy set with two outputs, a complete portable oxygen therapy device with manual respirator and Guedel cannula of all sizes and spare oxygen bottle, automated external defibrillator (AED), wheelchairs, rescue carts and individual safety rope, life jackets and rescue table or board.			
Rescue boat		1/beach	-	-
	Aquatic vehicle (jet type, propeller with protector, or water motorcycle) equipped with a stretcher; equipment for rescue, aid and evacuation; and a water-resistant marine transmitter. Plus, the same rescue equipment found at the surveillance points, lifejackets and a rescue bag.			
Vehicles		1 / beach	-	-
	This should be suitable for the kind of beach.			
Signposting		1 / access		
	Each signpost should display the following information: graphical description of the beach; flags and their meanings; location of surveillance, first aid and medical emergency points; boundaries of the monitored zone; recue service and hours; emergency phone 112 and location of nearest communication point. If the beach is closed, the reason for closure and the possible date of reopening should be indicated. If the beach is not monitored, this should be stated.			
Communica -tion		1 radio communication between lifeguards/surveillance points/ rescue and first aid points / directly with the 112		-
		1 loudspeaker system		-
Sea mark		1 specific sea mark system coexisting with boats and beach users, in accordance with regulations		-

[1]Each variable corresponding score is equal to 1 (good performance) when the level in which the criteria expressed is accomplished is high. On the other hand, if the level is partially achieved, the score is decreased to 0.5 (moderate situation); if it is not achieved, the score is decreased to 0 (bad situation). The final average outcome sums up the average score of each variable.

In the case of beaches presenting no surveillance and lifeguarding services, the final score was attributed as reported bellow:

	High risk ($<10m^2$ / user)	Medium risk ($10-60m^2$ / user)	Low risk ($>60m^2$ / user)
With signposting	0	0.5	0.9
Without signposting	0.2	0.7	1.0

This assessment should be carried out every time change the conditions of municipal biddings regarding lifeguarding services.

[2]Rather than using the level of urban development, this considers and differentiates between beaches in accordance with the established criteria for crowd risk.

B.9. Quality of surrounding area Sub-index

Landscape quality	
Impervious surface	Impervious Area / 500m Buffer Area
Coastal defense works against beach length	Beach coastal defense works / Total beach length
Water table enclosed by harbor and/or marine developments	Surface of water table closed by harbor developments /Total surface in 200m buffer in the maritime area
Aesthetic quality	
Impervious land use in the viewshed of the beach	> 60% impervious = 0
	20 - 60% = 0.33
	5- 20% = 0.66
	< 5% Impervious = 1

For this sub-index, all beach types are equally considered, therefore, no differentiation of scores is observed in this regard. The analysis, which should be carried out every 3 years, uses photographs taken from the beaches and aerial images. Results for the four variables (i.e. impervious surface, coastal defense works, water table and impervious land) are normalized to a range between 0 and 1, constituting their average the final outcome.

B.10. Current Conditions of Coastal Dune Systems of Developed Mediterranean Shores Sub-Index (Pintó, et al., 2014)

Variables[1]		Score[2]		
		1	**0.5**	**0**
Dune morphology parameters	Dune type	Foredune ridge followed by semifixed and/or fixed dunes	Foredune ridge only	Incipient forms, ramps, climbing dunes, and sand sheets
	Dune area (ha)	>15	5-15	<5
	Dune length / shoreline length (%)	>75	25-75	<25
	Mean height of dunes (m)	>2	1-2	<1
	Built environment (% area)	0	<20	>20
Human impact parameters	Car parking / car tracks (% area)	0	<20	>20
	Beach raking	Never	-	During tourist season
	Density of erosion of pathways (no. area)	$< 5x10^{-5}$	$5x10^{-5}$ to $5 x10^{-4}$	$>10^{-4}$
	Dune breaches (m)	<5	5-10	>10
	Invasive species (% area covered)	<5	5-10	>10
	Fixed dunes (% areas)	<25	25-50	>50

[Continuation of] Current Conditions of Coastal Dune Systems of Developed Mediterranean Shores Sub-Index (Pintó, et al., 2014)

Variables[1]		Score[2]		
		1	**0.5**	**0**
Dune-restricted plant system	Calculation: No. of plant species found in the dune system/ Potential no. of dune-restricted plant species) * 10	From 0 (no dune-restricted plant species found) to 10 (presence of all possible, listed, dune-restricted species for that biogeographic sector)		

[1]This sub-index is only applicable to Catalan sandy beaches and should be calculated every 3 to 5 years. Some of the data required may be available on the internet, e.g. dune type (Garcia-Lozano & Pintó, n.d.), but most of them should be obtained from fieldtrips or GIS analysis.
[2]The overall average outcome is calculated by the average of the normalized scores (in a range of 0 to 1) of three groups of variables: Dune morphology parameters, Human impact parameters, and Dune-restricted plant system.

B.11. State of water bodies (or masses) Sub-index

Classification[1,2]		Very good	Good	Sufficient	Insufficient	Bad
Physical-chemical (PC) status	Phosphates-Ammonias-Nitrites (Index FAN) in μmol/l[3]	FAN ≤ -0.2 or, FAN ≤ -0.3	-0.2 < FAN ≤ 0.2 or, -0.3 < FAN ≤ 0	0.2 < FAN ≤ 0.06 or, 0 < FAN ≤ 0.3	0.6 < FAN ≤ 1 or, 0.3 < FAN ≤ 0.6	FAN > 1 or, FAN > 0.6
	Preferred substances[4] in μg/l	-	Further details in Directive 2008/105/EC / (BOE, 2011)	-	-	Further details in Directive 2008/105/EC / (BOE, 2011)
	Total	IFAN = Very Good + Preferred substances = Good	IFAN = Good + Preferred substances = Good	IFAN = Sufficient + Preferred substances = Good	IFAN = Deficient + Preferred substances = Good	IFAN = Bad + Preferred substances = Good, or all the other combinations in which Preferred substances is = to Bad
Ecological (E) status (Biological quality)	*Posidonia oceanica* Multivariate Index (POMI) expressed by the Ecological Quality Ratio (EQR)	0.775 ≤ EQR ≤ 1	0.550 ≤ EQR < 0.774	0.325 ≤ EQR < 0.549	0.1 ≤ EQR < 0.324	EQR < 0.1
	Phytoplankton – Chlorophyll-a concentration[5] (EQR in μg/l)	EQR ≥ 0.82; EQR ≥ 0.83; or EQR ≥ 0.85	0.47 ≤ EQR < 0.82; 0.54 ≤ EQR < 0.83; or 0.61 ≤ EQR < 0.85	0.33 ≤ EQR < 0.47; 0.40 ≤ EQR < 0.54; or 0.50 ≤ EQR < 0.61	0.25 ≤ EQR < 0.33; 0.33 ≤ EQR < 0.40; or 0.42 ≤ EQR < 0.50	EQR < 0.25; EQR < 0.33; or EQR < 0.42

[Continuation of] State of water bodies (or masses) sub-index

Classification[1,2]		**Very good**	**Good**	**Sufficient**	**Insufficient**	**Bad**
Ecological (E) status (Biological quality)	Seaweeds - CARLIT method[6] (EQR of the dominant species in each section analyzed)	EQR > 0.75	0.60 < EQR ≤ 0.75	0.40 < EQR ≤ 0.60	0.25 < EQR ≤ 0.40	EQR ≤ 0.25
	Macro-invertebrates - MEDiterrània OCCidental Index (MEDOCC)	0 < MEDOCC < 1.6 and EQR > 0.73	1 ≤ MEDOCC < 3.2 and 0.47 < EQR ≤ 0.73	3.2 ≤ MEDOCC < 4.77 and 0.20 < EQR ≤ 0.47	4.77 ≤ MEDOCC < 5.5 and 0.08 < EQR ≤ 0.20	5.55 ≤ MEDOCC ≤ 6 and EQR ≤ 0.08
	Total	The average value corresponds to the average of the former attributes				
Total Score (PC + E status)[7]		Both are = to very good	PC = good + E = very good; PC = very good and E = good; PC and E = good	Whenever PC and E status or both are = to sufficient, except if, at least, one of them is ≤ deficient	Whenever PC and E status or both are = to deficient, except if, at least, one of them is = bad	Whenever PC and E status or both are = to bad
Chemical status	Priority substances[8] (in µg/l or mg/l)	-	Further details in Directive 2008/105/EC / BOE (2011) and Directive 2006/11/EC	-	-	Further details in Directive 2008/105/EC / BOE (2011) and Directive 2006/11/EC
	Total	-	Further details in Directive 2008/105/EC / BOE (2011) and Directive 2006/11/EC	-	-	Further details in Directive 2008/105/EC / BOE (2011) and Directive 2006/11/EC
Total Score (Ecological + Chemical)		-	1	0.5	-	0

[1]The corresponding assessment was produced by the Catalan Water Agency (ACA, n.d.) based on the criteria established in the Evaluation protocol for the ecological and chemical state of coastal bodies (ACA, 2013), which is an outcome of the quality standards established mainly by Directive 2000/60/EC, plus Directive 2008/105/EC and Directive 2006/11/EC. Future updates of the aforesaid protocol are already foreseen, such as inclusion of the criteria of Directive 2013/39/EU, and reconsideration of reference values and thresholds.
[2]The methodology offers a good capacity to detect massive water affectation on a medium scale (referring to water masses and yearly/decadal observations), but does present uncertainties regarding the identification of water affectation on small scales (e.g. for each beach in particular events).
[3]Respectively, values for the distance from the coast of between 0-50m and between 500- 1500m.

[4]Arsenic, copper, chrome VI, selenium, terbutylazine and zinc.
[5]The rank variations are due to the three types of continental influence on water bodies considered in Catalonia, respectively high, moderate and low.
[6]*Littoral Cartography* (Ballesteros, et al., 2007).
[7]The lowest value measured is the one considered in the analysis.
[8]Volatile organic compounds, polycyclic aromatic hydrocarbons, organochlorine pesticides, nonylphenol ethoxylates, polybromodiphenyl ethers, chloroparaffins, and metals.

B.12. Natural heritage Sub-index

			Score[1]					
Variable	**Source**	**Attributes**	**5**	**4**	**3**	**2**	**1**	**0**
Interest in conser-ving (IC) the most abundant habitat of each beach[2]	(Departament de Territori i Sostenibilitat, 2014a; Dept. de Territori i Sostenibilitat, 2014b)	General distribution within Europe	-	-	Western Mediterr a-nean	Mediterra-nean	Europe	-
		Frequency within the Catalan territory	Very rare	Rare	Quite common	Common	Very common	Un-certain or un-verified
		Form of territorial implementation	-	Very small surface	Small surface	Medium surface	Large surface	Un-certain or un-verified
		Biodiversity	-	-	High	Medium	Low	-
		Degree of maturity	-	-	Mature or stable	Not very mature	Essentially unstable	-
		Degree of threat	-	Highly threatened	Threa-tened	Probably threatened in the future	Not threa-tened	Un-certain or un-verified
			+ 0.2 (High)			**+ 0.1 (Medium)**	**0 (Extra value absent)**	
Marine Heritage[3]	(Departament de Territori i Sostenibilitat, 2014a; Dept. de Territori i Sostenibilitat, 2014b; Dept. d'Agricultura, Ramaderia, Pesca i Alimentació, 2018)	Those habitats found in the *midlittoral* and *infralittoral* zones presenting potential to develop bioconstructions or other unique formations	Habitats 11.24131+, 18.132 (= 11.252), 11.24132+, 11.2225+, 11.253+, and 18.112+ ; and/or, *Posidonia oceanica, Cymodocea nodosa, Zostera noltii, Caulerpa prolifera, Ruppia cirrhosa*			Habitats 11.2411+, 18.111+, 18.121+, 18.1313+, and 11.24121+	When the former habitats are not present	

[Continuation of] Natural heritage sub-index

Variable	Source	Attributes	Score[1]		
			+ 0.2 (High)	**+ 0.1 (Medium)**	**0 (Extra value absent)**
Natural protected areas	(Gencat, n.d.)	The legally stablished types of protected areas (from the Natura 2000 network and the Catalan Plan for Areas of Natural Interest-PEIN): National park, Natural site of national interest, undeveloped nature reserve, partial nature reserve and natural park	Existent	-	Nonexistent
Geo-logical Interest[4] within a radius of 300m from the beach	(Dept. de Medi Ambient, 1999)	Areas with geological interest (i.e. didactic, scientific or touristic) according to a group of experts that led a non-systematic qualitative evaluation of the later by comparing different sites of geological interest	Existent	-	Nonexistent

[1]For this sub-index, all beach types are equally considered, therefore, no differentiation of scores is observed in this regard. The final average score was calculated by summing up the average result of the IC of the most abundant habitat found at the beach (normalized between 0 and 1) with the potential extra scores of the other variables, when existent.
[2] Though here it is only considered the IC of the most abundant habitat of each beach, information regarding the IC of each the habitats found in the supra, mid and infra (-1m) littoral zones for each beach can be found at a scale of analysis of 1:1.500 to 1:2.000 (Departament de Territori i Sostenibilitat, 2014a; Dept. de Territori i Sostenibilitat, 2014b)
[3] The assignation of scores may not correspond entirely to those of the Gencat (i.e. the interest in conservation). The intention, however, is not to disagree with the extensive assessment undertaken by this organization, but to highlight the importance of potential bioconstructions or other unique biological formations, (e.g. (Desroy, et al., 2011; Templado, et al., 2015)
[4] In further developments, I suggest expansion to a more detailed scale of analysis and the consideration of a more robust methodology (e.g. (IELIG, 2013)).

B.13. Protection Sub-index

The harmful meteorological events of the last 10 years on the Catalan coast can potentially serve to identify those beaches that do not present the minimum capacity for serving as a buffer zone against energy coming from the sea, i.e. waves. For every harmful event affecting at least 1/3 of the longitude of the beach (e.g. damaged coastal infrastructure, such as a seafront promenade), 0.2 is deducted from an initial score of 1. If less than 1/3 is affected, 0.1 is deducted. Newspapers are the main source of data, so we are constrained by their reporting capacity (veracity and extent) on the aforesaid events. On the other hand, the concept of ease of use and adaptation to local specificities is more properly approached given that this analysis does not require as many resources as the one suggested in the protection sub-index of the SL-BQI (e.g. the call for *in situ* measurements and calculations for the whole Catalan coast). This method can also directly identify local events rather than applying the *Sbeach* model developed in the USA that, in order to estimate the relevant attributes (e.g. the storm surge), uses a standard beach profile and has not been calibrated to this specific study area.

B.14. Changes in physical processes Sub-index

I considered soft works (e.g. beach nourishment) done in the last 10 years as anthropic changes to physical beach processes. All calculations were carried out by comparing the volume of the engineering work, if ensued, to the volume of the beach. From an initial score of 1 (no soft work ensued), 0.5 was subtracted if the affectation corresponded to less than 30% of the total volume of the beach (considered moderate), and 1 was subtracted if the affectation corresponded to more than 30% (severe). For those beaches accumulating soft works during the period of time analysed, the average score was taken as the final outcome. The sources of data are the competent administrations on the matter; at the State level, this is the Ministry for Ecological Transition, and on the regional level, the Department of Territory and Sustainability. The major limitation related to using these sources is that non-official engineering works are disregarded. Like the protection sub-index, however, the application of the concept of the ease of use justified the substitution of the calculations and *in situ* measurements of the former attributes (e.g. changes in wave regime), which would require more resources, with the present ones.

B.15. Travel cost method (TCM)[26]

The TCM was included to assess the willingness of individuals to pay to visit a beach. This is indirectly measured using the costs incurred by beach users to perform this activity, such as travel costs - the distance to the beach, the type of transportation and the number of users per trip -, parking fee and the opportunity cost of time. These data are obtained from surveys of beach users. In practical terms, it is represented by the: 1) Individuals' willingness to pay to visit the beach (individual expenditure (€) / day), 2) Accumulated individuals' willingness to pay for this activity for the entire beach (total expenditure (€) / day). Note, however, a certain subjectivism regarding visiting costs. For example, the difficulty in defining the visitors exact place of origin, the role of substitute sites/activities when choosing the analyzed site and the fact that residents from the surrounding area may underestimate their real willingness to pay to visit the beach. This subjectivism calls for complementary methods if we expect a more reliable estimation of income from recreation (Randall, 1994). Moreover, the method was originally designed to be applied in National Parks (i.e. protected areas) (Hotelling, 1947) which are usually more isolated destinations (e.g. no accommodation is offered in the surroundings) than beaches. It might be therefore difficult to ascertain whether we are looking at the real capacity of a beach to attract visitors or the capacity of the surroundings to offer accommodation so users do not need to make longer journeys to another beach.

[26] Not carried out/presented in this thesis.

B.16. Contingent valuation (CV)[27]

The CV method was designed to estimate the value of assets and services for which there is no market, whereby a hypothetical market is created and tested using user surveys (Carson, 2000). In my case, by asking the questions "How much money from your annual taxes would you like to be used for the maintenance and management of this beach? And what should these maintenance and management actions be (e.g. beach cleaning, conservation measures, etc.)?" I would be able to estimate the percentage of individuals' taxes that beach users would assign to the aforesaid maintenance and management actions. The potential results are believed to support better allocation of resources, though there could be a certain level of subjectivity in users' responses (e.g. yea-saying practice which manifests when, with the aim of pleasing the surveyor, the user answers yes to a predefined question) (Carson, 2000). Finally, I should highlight that, in recent decades, the act of putting a monetary value on natural assets, processes or systems has been criticized due to its intrinsic narrowing of the existing plurality of non-commensurable values (Funtowicz & Ravetz, 1994).

[27] Not carried out/presented in this thesis.

APPENDIX C. AVERAGE DL-BQI OUTCOMES IN EACH OF THE BEACHES OBSERVED

In the following, I present the average outcomes of the DL-BQI sub-indexes for each of the beaches studied divided into sub-groups of urban, semi-urban and natural systems. Scores are highlighted in red when valued as bad, black when moderate and blue when good. Sub-indexes: MicrobioWQ = Microbiological water quality, Bcrow = Beach crowding, WasSewPOL = Waste and sewage pollution, ServFac = Services and Facilities, ConflictualACT = Conflictual activities, Access = Accessibility, ComfQ = Comfort Quality, Bsafety = Beach safety, SurroundQ = Quality of surrounding areas, CondDunes = Current conditions of dune systems; SWaterBodies = State of water bodies, NaturHER = Nature heritage, Changes PP = Changes in physical processes, and Protection.

Table C.1. Average scores found for each of the **urban beaches** evaluated in this study.

	Nº	**Beach**	**Municipality**	**Sub-indexes according to dimensions**													
				Recreational activity								**Ecology & Natural heritage**				**Morphodynamics**	
				Micro-bioWQ	**Bcrow**	**WasSew POL**	**ServFac**	**Conflic-tualACT**	**Access**	**ComfQ**	**Bsafe-ty**	**Surround Q**	**Cond-Dunes**	**S Water Bodies**	**Natur HER**	**Changes PP**	**Protec-tion**
Girona	1	De la Ribera*	El Port de la Selva	1.00	1.00	0.70	0.72	1.00	0.67	0.85	-	0.72	-	1.00	0.48	1.00	0.80
	2	Del Port	Llançà	1.00	1.00	0.60	0.47	0.40	0.67	0.68	0.44	0.64	-	1.00	0.65	1.00	1.00
	3	Empuria Brava	Castelló d'Empuries	0.90	0.60	0.60	0.80	0.70	0.63	0.75	0.69	0.36	0.46	0.50	0.76	1.00	1.00
	4	Gran d'Aro	Platja d'Aro	1.00	0.60	0.70	0.87	0.60	0.63	0.63	0.69	0.36	-	1.00	0.56	1.00	0.60
	5	Gran de Cadaqués*	Cada-qués	1.00	1.00	0.90	0.19	0.90	0.42	0.62	0.00	0.69	-	1.00	0.48	1.00	0.60
	6	Gran de Portbou	Port-bou	1.00	1.00	0.90	0.74	0.90	0.67	0.63	0.00	0.95	-	1.00	0.48	1.00	0.80
PD	*Bad weather in the day of the fieldtrip																

[Continuation of Table C.1]. Average scores found for each of the **urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & Natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Girona	7	L'Estartit	Torroella de Montgrí	1.00	0.00	0.80	0.47	0.60	0.83	0.72	0.63	0.48	0.33	1.00	0.65	1.00	0.80
	8	Llafranc	Palafrugell	1.00	0.60	0.90	0.63	0.90	0.83	0.68	0.63	0.33	-	1.00	0.85	1.00	1.00
	9	Lloret	Lloret de Mar	1.00	0.00	0.60	0.53	0.90	0.71	0.67	0.88	0.37	-	1.00	0.65	1.00	1.00
	10	Mar Menuda	Tossa de Mar	1.00	0.00	1.00	0.36	0.90	0.54	0.62	0.81	0.40	-	1.00	0.65	1.00	0.60
	11	s'Abanell (Nord)	Blanes	1.00	0.60	0.50	0.63	0.60	0.63	0.62	-	0.35	-	1.00	0.66	0.50	-0.20
	12	Sant Antoni	Calonge i Sant Antoni	1.00	0.60	0.90	0.66	0.80	0.67	0.57	0.81	0.46	-	1.00	0.44	1.00	0.80
	13	Sant Feliu	Sant Feliu de Guíxols	1.00	0.60	0.20	0.79	0.70	0.63	0.63	0.88	0.29	-	1.00	0.56	1.00	1.00
Barcelona	14	Barceloneta	Barcelona	0.90	0.00	0.70	0.76	0.70	0.83	0.54	0.88	0.21	-	0.50	0.45	0.50	0.60
	15	Bogatel	Barcelona	0.90	0.60	0.50	0.86	0.60	0.88	0.58	0.88	0.30	-	0.00	0.36	0.00	0.80
	16	Can Villar	Sant Pol de Mar	1.00	0.00	0.60	0.75	0.80	0.38	0.67	0.63	0.25	-	1.00	0.36	1.00	1.00

[Continuation of Table C.1]. Average scores found for each of the **urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & Natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Barcelona	17	Canet	Canet de Mar	1.00	0.60	0.60	0.90	0.80	0.46	0.61	0.63	0.34	-	1.00	0.36	1.00	1.00
	18	De l'Estació	Sant Andreu de Llavaneres	1.00	0.00	0.70	0.66	0.70	0.42	0.47	0.44	0.16	-	1.00	0.85	1.00	1.00
	19	de la Riera	Caldes d'Estrac	1.00	0.00	0.90	0.60	0.70	0.63	0.56	0.50	0.34	0.29	1.00	0.36	1.00	1.00
	20	De les Barques	Sant Andreu de Llavaneres	1.00	0.60	0.60	0.78	0.70	0.50	0.56	0.44	0.30	-	1.00	0.85	1.00	1.00
	21	De les Llumine tes	Castell-defels	1.00	1.00	0.90	0.82	0.70	0.58	0.76	0.81	0.38	-	0.00	0.16	1.00	1.00
	22	Del Garbí	Calella	1.00	0.00	0.70	0.62	0.60	0.63	0.57	0.69	0.40	-	1.00	0.36	1.00	1.00
	23	del Masnou (Nord)	El Masnou	1.00	0.60	0.40	0.78	0.60	0.54	0.54	0.75	0.18	-	0.50	0.55	1.00	1.00
	24	del Varador *	Mataró	0.80	1.00	0.80	0.82	0.70	0.67	0.66	0.63	0.25	0.32	1.00	0.76	1.00	1.00

[Continuation of Table C.1]. Average scores found for each of the **urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & Natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Barcelona	25	Dels Pesca-dors*	Pineda de Mar	1.00	1.00	0.70	0.61	0.80	0.67	0.68	0.69	0.37	-	1.00	0.36	0.50	0.60
	26	L'Estany ol	Sitges	1.00	0.00	0.80	0.35	0.80	0.63	0.73	0.69	0.26	-	0.75	0.36	0.00	0.80
	27	Llarga de Cubelles	Cubelles	1.00	1.00	0.90	0.88	0.90	0.75	0.77	0.63	0.32	-	0.50	0.85	1.00	1.00
	28	Pont de Petroli	Badalon a	1.00	1.00	0.90	0.92	0.90	0.75	0.50	0.69	0.35	-	0.00	0.36	1.00	1.00
	29	Ribes Roges	Vilanova i la Geltrú	1.00	0.60	0.70	0.77	0.60	0.75	0.86	0.81	0.26	0.21	0.50	0.45	1.00	1.00
	30	Sant Joan	Montgat	1.00	0.00	0.90	0.54	0.50	0.67	0.63	0.81	0.32	-	0.50	0.76	0.50	1.00
	31	Sant Vicenç de Moltalt	Sant Vicenç de Moltalt	1.00	1.00	0.80	0.74	0.80	0.50	0.61	0.44	0.32	0.30	1.00	0.56	1.00	1.00
Tarragona	32	Altafulla	Altafulla	1.00	0.00	0.70	0.59	0.80	0.58	0.68	0.69	0.40	-	0.50	0.56	1.00	1.00
	33	Cunit (Sud)	Cunit	1.00	0.00	0.90	0.92	0.50	0.63	0.72	-	0.31	-	0.50	0.44	1.00	1.00
	34	D'en Forés	Cambrils	1.00	0.60	0.70	0.56	0.70	0.75	0.85	0.81	0.27	-	0.50	0.65	1.00	1.00

[Continuation of Table C.1]. Average scores found for each of the **urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & Natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Tarragona	35	De la Paella	Torredembarra	1.00	0.60	0.60	0.75	0.90	0.75	0.81	0.69	0.29	0.33	0.50	0.56	1.00	1.00
	36	Dels Capellans	Salou	0.80	0.00	0.70	0.46	0.70	0.75	0.81	0.69	0.36	-	0.50	0.56	1.00	1.00
	37	Garbí*	Sant Carles de la Ràpita	1.00	1.00	0.60	0.45	0.80	0.83	0.91	0.69	0.21	-	1.00	0.73	1.00	1.00
	38	Les cases d'Alcanar*	L'Alcanar	1.00	1.00	0.70	0.86	1.00	0.67	0.59	0.63	0.53	-	1.00	0.28	1.00	0.80
	39	Racó de Vila-seca	Vila-seca	1.00	0.00	0.90	0.79	0.50	0.58	0.77	0.75	0.27	0.27	0.00	0.46	1.00	1.00
	40	Segur	Calafell	1.00	0.00	0.90	0.73	0.90	0.63	0.76	0.88	0.29	0.35	0.50	0.65	1.00	1.00
	Total average			0.98	0.50	0.73	0.68	0.74	0.65	0.67	0.66	0.36	0.34	0.74	0.54	0.90	0.89
PD	*Bad weather in the day of the fieldtrip																

Table C.2. Average scores found for each of the **semi-urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Girona	41	Can Cristus	Calonge i Sant Antoni	1.00	0.00	0.90	0.65	0.70	0.25	0.57	0.81	0.38	-	1.00	0.56	1.00	1.00
	42	D'en Ros*	Cadaqués	1.00	1.00	0.90	0.86	0.80	0.35	0.53	0.50	0.74	-	1.00	0.82	1.00	1.00
	43	De la Farella **	Llançà	1.00	0.60	0.90	0.72	0.70	0.75	-	0.70	0.55	-	1.00	0.36	1.00	1.00
	44	De les Tonyines**	Llançà	1.00	0.60	0.90	0.86	0.90	0.60	-	0.50	0.37	-	1.00	0.55	1.00	1.00
	45	Del Rec del Molí	L'Escala	0.30	0.00	0.40	0.73	0.70	0.60	0.65	0.20	0.57	0.56	1.00	0.36	1.00	1.00
	46	Grau	Pals	1.00	0.00	0.80	0.48	0.60	0.75	0.76	0.63	0.78	0.61	1.00	0.44	1.00	1.00
	47	L'Almadrava	Roses	1.00	0.60	1.00	0.56	0.80	0.60	0.53	0.88	0.59	0.21	1.00	0.56	1.00	1.00
	48	Llorel gran**	Tossa de Mar	1.00	0.60	0.70	0.84	0.50	0.25	-	0.50	0.58	-	1.00	0.56	1.00	1.00
	49	Portlligat*	Cadaqués	1.00	1.00	0.90	0.50	0.90	0.10	0.67	0.50	0.94	-	1.00	0.85	1.00	1.00
	50	Racó de Begur	Begur	1.00	0.00	0.80	0.36	0.50	0.50	0.58	0.56	0.71	0.43	1.00	0.44	1.00	1.00

*Bad weather in the day of the fieldtrip

** Physical comfort attributes were not possible to measure due to difficulties associated to the sea weather

[Continuation of Table C.2]. Average scores found for each of the **semi-urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Girona	51	Riuet	L'Escala	0.80	0.00	0.70	0.51	0.70	0.35	0.75	0.75	0.56	0.62	1.00	0.56	1.00	1.00
	52	Sa Conca - dels Oriços	Castell - Platja d'Aro	0.90	0.60	0.70	0.62	0.90	0.40	0.58	0.81	0.54	-	1.00	0.85	1.00	1.00
	53	Sa Tuna	Begur	1.00	0.00	1.00	0.45	0.80	0.50	0.53	0.00	0.61	-	1.00	0.85	1.00	1.00
	54	Santa Cristina	Lloret de Mar	1.00	0.00	1.00	0.45	0.90	0.35	0.53	0.81	0.62	0.33	1.00	0.76	1.00	1.00
	55	Ses Torretes	Calonge i Sant Antoni	1.00	0.00	0.80	0.73	0.50	0.25	0.62	0.75	0.37	-	1.00	0.56	1.00	1.00
	56	Treumal	Blanes	1.00	0.00	1.00	0.56	1.00	0.35	0.53	0.81 ***	0.95	-	1.00	0.76	1.00	1.00
Barcelona	57	Aïguadolç	Sitges	1.00	0.00	0.60	0.40	0.90	0.80	0.81	0.75	0.39	-	0.75	0.55	1.00	1.00
	58	Cabrera	Cabrera de Mar	0.90	0.00	0.60	0.49	0.50	0.45	0.44	0.50	0.29	0.32	0.50	0.56	0.00	1.00
	59	Cavalló	Arenys de Mar	1.00	1.00	0.60	0.52	0.50	0.60	0.52	0.94	0.48	-	1.00	0.36	1.00	1.00
	60	Del Llevant	Santa Susanna	1.00	0.00	0.80	0.65	0.40	0.75	0.59	0.69	0.39	-	1.00	0.36	1.00	1.00

***The safety services are the same as those deployed at the Santa Cristina beach

[Continuation of Table C.2]. Average scores found for each of the **semi-urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	S Water Bodies	Natur HER	Changes PP	Protec-tion
	61	del Masnou (Sud)	El Masnou	0.90	0.00	0.60	0.86	0.70	0.70	0.59	0.75	0.27	-	0.50	0.56	0.00	1.00
	62	Del Pla	Canet de Mar	1.00	0.60	0.50	0.71	0.80	0.60	0.61	0.75	0.39	0.36	1.00	0.36	1.00	1.00
	63	Descàrrega	Premià de Mar	1.00	0.60	0.50	0.88	0.90	0.25	0.49	0.88	0.24	-	0.50	0.36	0.00	1.00
	64	Garraf	Sitges	0.80	0.00	0.40	0.65	0.70	0.80	0.68	0.69	0.44	-	0.75	0.56	1.00	1.00
	65	Musclera	Arenys de Mar	1.00	0.00	0.90	0.73	0.80	0.30	0.51	0.94	0.36	-	1.00	0.36	1.00	1.00
	66	Parc del Litoral ****	Sant Adrià del Besòs	0.80	1.00	0.80	0.76	0.70	1.00	0.45	0.63	0.31	-	0.00	0.36	1.00	1.00
	67	Punta de la Tordera *	Malgrat de Mar	1.00	1.00	0.90	0.86	1.00	0.75	0.49	0.75	0.55	-	1.00	0.56	0.33	0.40
Tarragona	68	Casa dels Lladres	Mont-roig del camp	1.00	1.00	1.00	0.81	0.70	0.55	0.72	0.94	0.56	0.23	1.00	0.56	0.50	1.00
	69	Creixell *	Creixell	1.00	1.00	0.90	0.84	0.60	0.85	0.81	0.75	0.56	0.72	0.50	0.76	1.00	1.00

*Bad weather in the day of the fieldtrip; **** In the context of the Metropolitan Area of Barcelona, it was considered semi-urban due to the presence of a small protected area in the surroundings (Besòs river mouth)

[Continuation of Table C.2]. Average scores found for each of the **semi-urban beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Tarragona	70	De la Mora	Tarragona	1.00	0.60	0.70	0.76	0.90	0.65	0.90	0.94	0.36	0.36	1.00	0.56	1.00	1.00
	71	De la Punta del Riu	Vandellós i l'Hospitalet de l'Infant	1.00	0.60	0.70	0.84	0.80	0.60	0.67	0.81	0.32	0.20	1.00	0.85	1.00	1.00
	72	Del Francàs	El Vendrell	1.00	0.60	1.00	0.83	0.50	0.75	0.71	0.81	0.32	0.32	0.50	0.56	1.00	0.60
	73	L'Almadrava	Vandellós i l'Hospitalet de l'Infant	1.00	0.60	1.00	0.93	0.80	0.60	0.86	0.81	0.45	0.16	1.00	0.56	1.00	1.00
	74	L'Arenal	L'Ampolla	1.00	1.00	0.70	0.47	0.50	0.45	0.86	0.75	0.80	0.48	1.00	0.56	0.50	1.00
	75	L'Estany	Ametlla de Mar	1.00	1.00	0.50	0.56	0.80	0.20	0.58	0.70	0.79	-	0.50	0.85	1.00	1.00
	76	Llarga de Tarragona	Tarragona	1.00	0.60	0.90	0.54	0.50	0.90	0.90	0.94	0.59	0.80	1.00	0.56	1.00	1.00
Total average				0.96	0.47	0.78	0.67	0.72	0.54	0.64	0.71	0.52	0.42	0.88	0.57	0.87	0.97

Table C.3. Average scores found for each of the **natural beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafe-ty	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Girona	77	Cal Cristià	Sant Pere Pescador	1.00	0.60	1.00	0.88	0.70	0.53	0.70	0.94	0.80	0.46	1.00	0.56	1.00	1.00
	78	Cala Montjoi	Roses	1.00	1.00	1.00	0.66	0.50	0.50	0.67	0.70	0.82	-	1.00	0.96	1.00	1.00
	79	Can Comes*	Castelló d'Empuries	1.00	1.00	0.70	0.93	1.00	0.00	0.71	0.00	0.98	0.59	0.50	0.76	1.00	1.00
	80	Can Nera	Sant Pere Pescador	1.00	0.60	0.80	0.66	0.70	0.53	0.75	0.94	0.96	0.46	1.00	0.56	1.00	1.00
	81	Castell	Palamós	1.00	0.00	0.60	0.37	0.50	0.58	0.57	0.94	1.00	0.56	1.00	0.46	1.00	1.00
	82	De la Murtra	Roses	1.00	0.00	0.90	0.88	0.80	0.63	0.49	0.00	1.00	-	1.00	1.05	1.00	1.00
	83	Garbet	Colera	1.00	1.00	0.80	0.61	1.00	0.50	0.58	0.50	0.96	0.35	1.00	1.02	1.00	1.00
	84	Golfet	Palafrugell	1.00	0.00	1.00	0.85	0.80	0.63	0.45	0.00	0.94	-	1.00	0.75	1.00	1.00
	85	Senyor Ramon	Santa Cristina d'Aro	1.00	1.00	0.90	0.82	0.90	0.38	0.49	0.70	0.95	-	1.00	0.85	1.00	1.00

*Bad weather in the day of the fieldtrip

[Continuation of Table C.3]. Average scores found for each of the **natural beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafety	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Barcelona	86	Cala la Ginesta	Sitges	1.00	0.60	0.90	0.47	0.80	0.55	0.82	0.88	0.23	0.44	0.75	0.65	1.00	1.00
	87	De la Pineda	Viladecans	1.00	0.60	0.70	0.46	0.80	0.53	0.81	0.75	0.93	0.59	0.00	0.36	1.00	1.00
	88	Del Remolar**	El Prat de Llobregat	1.00	1.00	0.70	0.76	0.80	0.85	0.77	0.69	0.96	0.74	0.00	0.36	1.00	1.00
Tarragona	89	Cala Fonda	Tarragona	1.00	1.00	1.00	0.91	0.90	0.50	0.90	0.70	0.98	-	1.00	0.56	1.00	1.00
	90	De Becs	Tarragona	1.00	1.00	1.00	0.91	0.80	0.50	0.77	0.70	1.00	-	1.00	0.93	1.00	1.00
	91	De Buda ***	Sant Jaume d'Enveja	-	-	0.60	-	-	-	-	-	1.00	0.64	1.00	0.36	1.00	1.00

**Fishing activities are allowed

***General public access to this beach is not allowed, so that indexes related to users satisfaction were not measured and prioritized

[Continuation of Table C.3]. Average scores found for each of the **natural beaches** evaluated in this study.

	Nº	Beach	Municipality	Sub-indexes according to dimensions													
				Recreational activity								Ecology & natural heritage				Morphodynamics	
				Micro-bioWQ	Bcrow	WasSew POL	ServFac	Conflic-tualACT	Access	ComfQ	Bsafety	Surround Q	Cond-Dunes	SWater Bodies	Natur HER	Changes PP	Protec-tion
Girona	92	Dels Eucaliptus	Amposta	1.00	1.00	0.70	0.49	0.60	0.23	0.86	0.70	0.98	0.26	1.00	0.36	1.00	1.00
	93	El Trabucador	Sant Carles de la Ràpita	1.00	1.00	0.50	0.88	0.70	0.13	0.86	0.90	1.00	0.40	1.00	0.56	1.00	1.00
	94	La Marquesa	Deltebre	1.00	1.00	0.50	0.79	0.80	0.20	0.95	0.50	1.00	0.62	1.00	0.56	0.50	0.40
	95	Sant Jordi	Ametlla de Mar	1.00	0.00	0.90	0.42	0.70	0.33	0.95	-	0.75	0.41	0.50	0.76	0.50	1.00
	96	Santa Llúcia	El Perelló	1.00	1.00	0.90	0.76	0.90	0.13	0.63	-	0.93	-	0.50	0.56	0.50	1.00
Total average				1.00	0.72	0.81	0.71	0.79	0.43	0.72	0.62	0.91	0.44	0.81	0.65	0.93	0.97