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PhD DISSERTATION

A Systems Approach to Identify Indicators for Integrated Coastal Zone Management

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Abstract

The problem addressed by this thesis is the identification of site-specific and problem-oriented sets of indicators, to be used to determine baseline conditions and to monitor the effect of ICZM initiatives.

The approach followed integrates contributions from coastal experts and stakeholders, systems theory, and the use of multivariate analysis techniques in order to provide a cost-effective set of indicators, oriented to site-specific problems, with a broad system perspective.

A systems approach, based on systems thinking theory and practice, is developed and tested in this thesis to design models of coastal systems, through the identification of the system's components and relations, using the contribution of experts and stakeholders.

Quantitative analysis of the system is then carried out, assessing the contribution of stakeholders and using multivariate statistics (principal components analysis), in order to understand the structure of the system, including relationships between variables.

The simplification of the system (reduction of the number of variables) is one of the main outcomes, both in the participatory system's design and in the quantitative multivariate analysis, aiming at a cost-effective set of key variables to be used as indicators for coastal management.

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List of the main acronyms

AECID Spanish Agency for International Cooperation and Development

BSC Balanced Score Card

CAMP Coastal Area Management Programme

CAS Complex Adaptive Systems

CLD Causal Loop Diagram

CZMA Coastal Zone Management Act

DGC-MMA Coastal Directorate General – Spanish Ministry of the Environment

DPSIR Driving forces Pressures Impacts States Responses

EC European Commission

ESI Environmental Sustainability Index

EU European Union

GDP Gross Domestic Product

GIZC Gestión Integrada de las Zonas Costeras

GMB Group Model Building

GST General System Theory

HDI Human Development Index

ICOM Integrated Coastal and Ocean Management

ICZM Integrated Coastal Zone Management

IOC - UNESCO Intergovernmental Oceanographic Commission - United Nations Educational, Scientific and Cultural Organization

JRC Joint Research Centre of the European Commission

MAP Mediterranean Action Plan

MIT Massachusetts Institute of Technology

MSICZMP Matruh Sallum ICZM Plan

MTPD Maritime-Terrestrial Public Domain

MVA Missing Values Analysis

NCMP National Coastal Management Programme

NOAA National Oceanic and Atmospheric Administration

NTU Nephelometric Turbidity Units

OECD Organization for Economic Co-operation and Development

COSVA Cantabria Oil Spill Vulnerability Atlas

PAP-RAC Priority Actions Programme - Regional Activity Centre

PCA Principal Component Analysis

PCM Participatory Causal Matrix

PSR Pressure State Response

SCS Spanish Strategy for Coastal Sustainability

SD Systems Dynamics

SEM Structural Equation Modeling

SFD Stock and Flows Diagrams

SSM Soft Systems Methodology

ST Systems Thinking

SWOT Strengths Weaknesses Opportunities Threats

UN United Nations

UNCED United Nations Conference on Environment and Development

UNEP United Nations Environment Programme

VSM Viable Systems Model

WG-ID Working Group on Indicators and Data

WG-SCSI Working Group on Spanish Coastal Sustainability Indicators

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RESUMEN EN CASTELLANO

1. Introducción

A lo largo de los últimos años se han llevado a cabo diversos trabajos centrados en la identificación de sistemas de indicadores de carácter general que permitan medir el estado de la costa y su progreso hacia el desarrollo sostenible.

Tales sistemas generales de indicadores resultan muy útiles para realizar análisis comparados entre distintas zonas geográfica, no obstante, su uso resulta limitado a la hora de plantear el diseño y la implementación de planes de gestión específicos.

Así, esta tesis parte de la idea de que los sistemas de indicadores, utilizados para medir el estado de la costa y la implementación de proyectos de Gestión Integrada de las Zonas Costeras (GIZC), deben orientarse a problemas concretos de la zona de estudio y que su validez debe ser comprobada no sólo por la opinión de los expertos, sino también por la percepción de los usuarios y por el análisis estadístico cuantitativo.

El objetivo de la tesis es establecer un marco metodológico para la identificación de indicadores GIZC orientados a problemas y temas de interés, para contextos geográficos específicos.

Para alcanzar este objetivo, se ha orientado la investigación a la resolución de tres cuestiones clave:

1. ¿Cómo identificar los actores, los problemas y los temas de interés que puedan afectar el desarrollo sostenible de las zonas costeras?

2. ¿Cómo construir modelos de funcionamiento del sistema que incluyan todos los elementos identificados?

3. ¿Cómo analizar de manera cuantitativa tales elementos para identificar las variables críticas que puedan ser utilizadas como indicadores de gestión?

La investigación, caracterizada por un sólido enfoque multidisciplinar, cubre el estado del arte en las metodologías GIZC en las disciplinas que tradicionalmente se han aproximado al problema (gestión medioambiental, ingeniería costera, geografía regional) y explora las posibles contribuciones de disciplinas más ligadas al mundo de las ciencias sociales, la gestión empresarial y la macroeconomía, como las ciencias sistémicas, el análisis de las políticas públicas, la econometría y la estadística multivariante.

De ahí el desarrollo de un marco metodológico que integra técnicas de participación pública (para la identificación e implicación de expertos y actores) con técnicas sistémicas (para delimitar el problema e identificar las variables de interés) y técnicas de estadística multivariante (para identificar las variables más relevantes para el sistema).

Esta tesis se desarrolla en el contexto actual de la GIZC a nivel nacional e internacional, marcado por la Recomendación Europea sobre GIZC (2002) que ha impulsado varias iniciativas a nivel nacional (como la Estrategia para la Sostenibilidad de la Costa del Ministerio de Medio Ambiente), por varias directivas sectoriales con efectos sobre la costa (Directiva Marco sobre Aguas, Directiva sobre Inundaciones, Directiva sobre la Estrategia Marina, etc.), y por el reciente Protocolo sobre GIZC para el Mediterráneo (2008).

Varios proyectos de gestión costera, llevados a cabo en los últimos cuatro años, han servido como base para aplicar y contrastar las distintas metodologías. Las experiencias más relevantes incluyen la Estrategia para la Sostenibilidad de la Costa del Ministerio de Medio Ambiente, el proyecto MSICZMP, que pretende desarrollar un plan de GIZC para la costa Mediterránea de Egipto y el proyecto Europeo DEDUCE sobre la aplicación del sistema europeo de indicadores GIZC a la costa de Cataluña.

2. Estado del arte: las ciencias sistémicas y el uso de indicadores

La Gestión Integrada de las Zonas Costeras (GIZC) surge como un proceso para la aplicación de los principios del desarrollo sostenible (funcionalidad natural, eficiencia económica y equidad social) en las zonas costeras, a través de un conjunto de buenas prácticas de gestión.

La GIZC está estrictamente relacionada con las ciencias sistémicas y el uso de indicadores: el enfoque sistémico aplicado a la gestión siempre ha sido básico en la teoría y la práctica GIZC, y la descripción y el seguimiento del sistema necesita a su vez de información en forma de indicadores que asistan a los gestores en su toma de decisiones.

Las ciencias sistémicas se han ido desarrollando a lo largo de los últimos 60 años en ámbitos tan dispares como la ingeniería industrial (Forrester, 1968) y la ecología (Odum, 1983), para modelar la estructura, simular el comportamiento y estudiar propiedades emergentes de los sistemas complejos. Por sistema se entiende una serie de entidades interdependientes que forman un conjunto integrado.

Las teorías, investigaciones y aplicaciones desarrolladas en el marco de las ciencias sistémicas incluyen la cibernética (Wiener, 1948), la teoría general de los sistemas (Von Bertalanffy, 1968), la dinámica de los sistemas y el pensamiento sistémico (Checkland, 1981; Senge, 1990; Sterman, 2000). Cada una de estas ramas ha contribuido esencialmente al desarrollo de técnicas diferentes dependiendo de los ámbitos de aplicación, pudiéndose distinguir entre técnicas duras (como el modelado numérico de los procesos en sistemas económicos o industriales) y blandas (por ejemplo, las técnicas de construcción de modelos mentales compartidos en sistemas socio-ambientales). Las ciencias sistémicas se han desarrollado sobre todo para resolver problemas económicos y de gestión o para el análisis de políticas públicas, aunque han tenido un uso limitado en la GIZC. Sin embargo, existen referencias teóricas relevantes sobre la potencialidad del uso de la teoría de sistemas (Van Der Weide, 1993; Vallega, 1999) y de la cibernética organizacional (Kay et al., 2003) en la GIZC. Así, el proyecto SPICOSA (SPICOSA WP3, 2007) está llevando a cabo simulaciones sistémicas en sitios pilotos a lo largo de las costas europeas.

A su vez, el uso de indicadores es común a muchas disciplinas, siendo posiblemente la econometría (Nardo et al., 2005) y la medicina (WHO, 2008) los ámbitos donde más se ha avanzado en la identificación y en el diseño de indicadores más o menos complejos, combinando el conocimiento del funcionamiento del sistema con el desarrollo de herramientas estadísticas avanzadas. Conviene señalar que por indicador se entiende una variable o un conjunto de variables, combinadas o sin combinar, representativas del estado de un sistema. Los indicadores han de cumplir, entre otras características, que sean fácilmente medibles y repetibles, sensibles a cambios en el sistema y comprensibles para los usuarios finales.

Por ejemplo, en algunos casos es suficiente medir una única variable como representativa del estado de un sistema: es este el caso de las emisiones de carbono para monitorizar el cambio climático. En otros casos es necesario representar un sistema por un conjunto de variables: es este el caso, por ejemplo, de los indicadores estructurales de la EU (Eurostat, 2009). A través de la combinación de las variables es posible también construir indicadores agregados, como el Producto Interior Bruto (PIB) o el índice de desarrollo humano (HDI) (UNDP, 2009).

El uso de indicadores para la GIZC se ha ido consolidando en la última década, con un aumento de la producción científica al respecto (Bowen et al. 2003; Ehler, 2003; Hanson, 2003; Henocque, 2003; Olsen, 2003; Rice, 2003; Jiménez et al. 2004; Pickaver et al., 2004; Sardá et al., 2005; Potts, 2006; Conway, 2007; Fontalvo-Herazo et al., 2007; Rey-Valette et al., 2007; Hoffmann, 2007). Así existen propuestas de sistemas de indicadores para medir el estado de la costa a nivel Europeo (Breton, 2006) y casos prácticos de implantación de sistemas de indicadores costeros (NOAA, 2007). La identificación de los indicadores representativos del sistema costero se suele basar en modelos teóricos (PER, FPEIR, HGF) o en la opinión de expertos. El uso de técnicas sistémicas no es tan común, aunque existen ciertas experiencias en este sentido (ver, por ejemplo, Fontalvo-Herazo, 2007). El uso de técnicas estadísticas para la identificación de la información más relevante es asimismo poco común aunque técnicas como el análisis de componentes principales ya hayan sido utilizadas en casos concretos (ver, por ejemplo, Shi et al., 2004).

En conclusión, el análisis del estado del arte en las ciencias sistémicas y en el uso de indicadores realizada ha permitido identificar las posibles carencias y las oportunidades para nuevos desarrollos metodológicos para la GIZC, que integren enfoque sistémico y la participación pública con técnicas estadísticas multivariantes.

3. Exploración de sistemas costeros

El capítulo 3 de la tesis se ha enfrentado a la exploración de los sistemas costeros, incluyendo la identificación de actores, la formulación de problemas y la producción de diagnósticos integrados, basados en la integración del conocimiento de los expertos con la opinión y percepción de los actores locales.

Este capítulo se ha centrado en la primera cuestión clave:

¿Cómo identificar los actores, los problemas y los temas de interés que puedan afectar el desarrollo sostenible de las zonas costeras?

A lo largo del capítulo se ha llevado a cabo una reflexión crítica, formalizada en el seno del análisis de las políticas pública cómo ámbito disciplinar, sobre distintas experiencias en el ámbito GIZC.

La gestión integrada se enfrenta comúnmente a problemas complejos e inestructurados, donde los aspectos técnicos se cruzan con múltiples intereses y puntos de vista. Un análisis sistémico y estructurado es entonces necesario para poder enmarcar la complejidad a través de una correcta formulación y diagnóstico de los problemas analizados, basada en la integración del conocimiento técnico de los expertos con la percepción de los actores interesados.

A la hora de implementar proyectos en la costa, el enfoque sistémico es fundamental para identificar las componentes del sistema que puedan verse afectadas por las decisiones tomadas. Los proyectos que se llevan a cabo en los sistemas socio-ambientales complejos deben considerar todas las componentes del sistema, incluyendo el subsistema físico, el ecológico, el social, el económico y el administrativo.

En ese sentido, la correcta formulación del problema, sobre todo en sistemas socio-ambientales complejos, requiere la identificación e implicación de los actores públicos y privados que tienen interés sobre el medio analizado. Una correcta identificación de los actores interesado es fundamental para asegurar la correcta identificación del alcance del las acciones tomadas, para poder compartir la responsabilidad de las decisiones y para alcanzar un nivel de consenso que asegure el éxito de las iniciativas propuestas.

Para apoyar las ideas y el enfoque tomado para la exploración de los sistemas costeros, se han reportado y analizado distintos casos de estudio, en los cuales: (i) se han aplicado técnicas para la identificación y clasificación de actores para la GIZC, a nivel nacional (ii) se ha valorado el proceso de formulación del problema y de identificación de alternativas, para un sistema de playas en erosión (Italia) (iii) se han involucrado actores y expertos en la construcción de un diagnóstico integrado (Egipto) y (iv) se ha llevado a cabo un taller de expertos para la identificación de las componentes y variables para el sistema de indicadores de sostenibilidad del litoral español. Seguidamente se detallan los cuatro casos de estudio.

El primer caso ha tratado las técnicas de identificación de actores. Este caso se basa en la experiencia del inventario de actores desarrollado en respuesta a la Recomendación 413/2002/CE sobre la Gestión Integrada de las Zonas Costeras en Europa, llevado a cabo para la Dirección General de Costas del Ministerio de Medio Ambiente, Rural y Marino (Ministerio de Medio Ambiente, 2006). Para realizar el inventario se ha desarrollado una técnica iterativa para la identificación de los actores costeros a través de entrevistas. La técnica empleada, denominada “Hidra” (una cabeza genera más cabezas) permite generar un listado completo de actores partiendo de una problemática concreta. Así un primer listado, generado por las Demarcaciones de Costas del MARM, fue utilizado para contactar con determinados actores que a su vez identificaban aquellos actores faltantes. Sucesivamente se preguntaba a los nuevos actores para completar la lista, hasta que todos los actores estuvieran conectados entre ellos. Se ha comprobado que, comúnmente, el círculo de preguntas se cierra en tres rondas.

El segundo caso de estudio corresponde a un proyecto de regeneración de playas en el Ayuntamiento de Finale Ligure, Italia (IH Cantabria, 2008). En este caso se ha comprobado que la formulación del problema inicial enunciado por el ayuntamiento representaba un punto de vista y un interés concreto, es decir el mantenimiento de las playas con el mínimo esfuerzo técnico-económico. La identificación e implicación de otros sectores de la administración pública, a nivel regional y provincial, y de otros actores sociales, ha permitido ver el problema desde distintas perspectivas e identificar los puntos críticos que pueden afectar el éxito final del proyecto. En total, se han identificado ocho actores clave que han sido invitados a participar en un encuentro público, durante el cual se han expuesto los distintos intereses y preocupaciones. Por otro lado se ha testado una técnica común en la gestión de negocios, el llamado cuadro de mando integral (*balanced score-card*), una herramienta útil para poder comparar el efecto de distintas soluciones alternativas sobre todas las componentes de interés del sistema, para el cual se ha utilizado un sistema de 16 indicadores.

El tercer caso de estudio se basa en las labores realizadas para el Proyecto MSICZMP, que pretende desarrollar un plan de GIZC para la costa Mediterránea de Egipto (IH Cantabria, 2007). Para este proyecto se ha llevado a cabo un diagnóstico técnico, para el cual se ha contado con la participación de expertos sectoriales, y que a su vez ha completado con las contribuciones de los actores locales, a través un taller de participación pública. Para este taller se han diseñado fichas específicas que permiten recoger la información y las opiniones de los actores con respecto al diagnóstico técnico realizado. Con este caso de estudio se ha demostrado como el diagnóstico técnico no es suficiente para poder identificar actuaciones prioritarias, sobre todo en una zona geográfica poco conocida y donde las soluciones basadas sólo en el diagnóstico técnico pueden tener importantes implicaciones sobre otras componentes del sistema. Por otro lado se ha confirmado la necesidad de identificar indicadores para la GIZC que estén orientados a problemas concretos del área, ya que sistemas de indicadores generales son difícilmente aplicables y poco útiles para medir los problemas detectados y poder evaluar el efecto de las soluciones propuestas.

El cuarto caso se basa en la participación en el Grupo de Trabajo sobre Indicadores (GTI) de Sostenibilidad del Litoral Español (Martí et al., 2007). El objetivo del trabajo fue la construcción de un sistema de indicadores a través de la contribución de expertos de distintos ámbitos costeros, tanto científicos como técnicos. El marco de trabajo para la identificación de los indicadores estaba representado por ocho retos y 21 indicadores que deberían ser utilizables para medir el estado de la costa en España. El enfoque de este Grupo de Trabajo se aleja claramente del objetivo de la tesis, ya que los indicadores del GTI buscan la construcción de un sistema de medición único exportable a contextos geográficos diferentes. A pesar de estas diferencias, las conclusiones del GTI enfatizan la necesidad de identificar las posibles relaciones causales y las redundancias y correlaciones internas al sistema de indicadores. Esta tesis propone dos maneras concretas para enfrentarse a este problema: la construcción de modelos de funcionamiento del sistema basados en técnicas sistémicas, y el uso de técnicas de análisis multivariante para identificar las correlaciones y dependencias entre variables.

4. Técnicas sistémicas y participación pública

Esta parte de la tesis, que corresponde al capítulo 4, versa sobre la identificación y el desarrollo de técnicas sistémicas que permitan dirigir la contribución de los expertos y de los actores hacia la construcción de un modelo compartido.

Este capítulo se ha centrado en la segunda cuestión clave:

¿Cómo construir modelos de funcionamiento del sistema que incluyan todos los elementos identificados?

Se propone aquí la adaptación de técnicas existentes y el desarrollo de nuevas en el ámbito del pensamiento sistémico (*systems thinking*) para la construcción de modelos mentales compartidos, basados en técnicas participativas.

El pensamiento sistémico (PS) trata de acercarse a la resolución de problemas complejos considerándolos como parte de un sistema más amplio y teniendo en cuenta los posibles efectos que puedan tener distintas alternativas y políticas sobre otras componentes del sistema (ver, por ejemplo, Sterman, 2000). Esta disciplina plantea considerar los sistemas (industriales, económicos, sociales, naturales) como un conjunto de elementos (variables) conectado causalmente; para modelar tales sistemas existen varias técnicas, centradas en la identificación de los elementos que componen el sistema y de las relaciones que conectan tales elementos. La técnica básica del pensamiento sistémico consiste en el uso de diagramas causales que se utilizan para conectar las distintas variables y para identificar bucles de retroalimentación y otras estructuras recurrentes, llamadas arquetipos o patrones de comportamiento (Senge, 1990). Por otro lado, los diagramas causales se pueden transformar en diagramas de flujo más complejos que permiten la simulación cuantitativa de distintos escenarios, mediante la asignación de valores iniciales a las distintas variables que componen el sistema (Binder, 2008). Un paradigma clave del pensamiento sistémico es el denominado “modelo mental”, es decir, la representación de la realidad en la mente de un actor del sistema. Asimismo, un importante reto del PS es mejorar la representación y la comprensión del sistema en su conjunto, incluyendo todas las variables y relaciones que puedan afectar los distintos sectores de la sociedad. La construcción de modelos mentales compartidos, en forma de diagramas causales, ayuda de esta manera a la comprensión y el consenso entre los actores involucrados (ver, por ejemplo, Elias, 2006).

En esta tesis se ha propuesto una metodología basada en nuevas técnicas de grupo para la construcción de modelos de sistemas complejos y para poder identificar las variables críticas basándose en la contribución de actores y expertos.

La metodología empleada se divide en distintos pasos, que se ilustran a continuación:

1. Identificación de las variables del sistema por parte de los actores involucrados (por ejemplo: erosión costera, contaminación de las aguas, intrusión salina, desarrollo urbano etc.).

2. Realización de la matriz de interacciones causales, donde actores y expertos identifican las posibles relaciones causales basándose en su propio modelo mental del sistema.

3. Solapamiento de las diferentes matrices causales y creación de un modelo mental compartido a través del uso de diagramas causales.

4. Cálculo de la importancia relativa de cada variable del sistema en términos de recurrencia entre los participantes y el número de elementos afectados.

Los resultados de la construcción de un modelo del sistema, basado en la contribución de expertos sectoriales y actores locales permiten de esta forma identificar las variables más relevantes del sistema, utilizables como sistema de indicadores preliminar.

La metodología se ha aplicado a un caso teórico y a dos casos reales, para poder comprobar su aplicabilidad:

El primer caso de estudio corresponde a una simulación en la cual cuatro actores contribuyen en la construcción de un modelo mental compartido. A través de este caso se ha comprobado la aplicabilidad de las matrices causales para la construcción de modelos mentales compartidos y su transformación en diagramas causales que representen el sistema en su conjunto. Sucesivamente se ha desarrollado un algoritmo que permite combinar la contribución de los actores con la importancia de cada elemento en términos de efecto sobre el sistema.

El segundo caso de estudio corresponde al proyecto de regeneración de playas en el Ayuntamiento de Finale Ligure, en Italia, que se empezó a analizar en el capítulo precedente. A pesar de no haber podido realizar un taller de participación real, se ha realizado una simulación utilizando los datos disponibles y el conocimiento de experto, que ha puesto de manifiesto que, a través de la construcción de un modelo de funcionamiento del sistema, es posible detectar las variables más relevantes. Los resultados de este ejercicio confirman la existencia de variables cuyo control es clave para el funcionamiento del sistema: estas variables, que corresponden a la cantidad del vertido y a la calidad de la arena, están claramente identificadas a priori por los técnicos. En otros casos, más complejos, la explicitación de modelos mentales puede ayudar a desvelar variables clave desconocidas: es este el caso del proyecto GIZC en Egipto.

El proyecto GIZC en Egipto se ha utilizado como tercer caso de estudio. Tres técnicos involucrados en el proyecto han contribuido a la construcción de un modelo mental compartido. Los resultados, analizados de manera cuantitativa para identificar los elementos del sistema que más importancia tienen en términos de recurrencia entre los participantes y número de elementos afectados, reflejan algunos de los problemas reales de la zona, como el desarrollo urbanístico en la costa, el desarrollo agrícola y la designación de áreas protegidas.

En conclusión, en esta parte de la tesis se ha desarrollado una metodología para poder construir modelos de sistemas que incluyan variables y relaciones, basados en la contribución de actores locales y expertos sectoriales. Esta metodología se ha aplicado a un caso teórico y a dos casos reales, utilizando los datos aportados por los expertos involucrados en tales proyectos.

El proceso de modelización de grupo tiene varias ventajas: (i) favorece el acercamiento de los puntos de vista de los participantes y la creación de consenso (ii), identifica los elementos clave del sistema como base para los análisis cuantitativos y (iii) proporciona los datos necesarios para priorizar estos elementos para que puedan ser utilizadas como indicadores (en el caso en que los datos necesarios para los análisis estadísticos no estén disponibles).

5. Estadística multivariante para el análisis de sistemas

En esta parte de la tesis, que corresponde al capítulo 5, se ha testado una técnica de análisis multivariante, el análisis de las componentes principales (PCA), para el análisis de sistemas de variables.

Este capítulo se ha centrado en la tercera cuestión clave:

¿Cómo analizar de manera cuantitativa tales elementos para identificar las variables críticas que puedan ser utilizadas como indicadores de gestión?

El PCA ha sido seleccionado como la técnica más apropiada para el análisis del sistema ya que identifica los grupos de variables que aportan más información, en términos de varianza explicada, asegurando la ortogonalidad (independencia) entre las variables analizadas.

El análisis de componentes principales es una técnica que se aplica para reducir la dimensionalidad de conjuntos de variables, y así retener las variables más significativas. Para ello, el PCA agrupa n variables en n componentes ortogonales entre ellas, de las cuales $p<n$ variables recogen la mayor parte de la varianza del conjunto de variables. Como criterio general, se retienen las variables que quedan agrupadas en las componentes principales que contribuyen como mínimo al 10% de la varianza explicada. De esta manera se retienen las variables más importantes sin perder mucha de la información en términos de varianza. El PCA proporciona, además de agrupar las variables en componentes, también las cargas factoriales de cada variable, es decir el peso de cada variable por cada componente. Esta información se puede utilizar sucesivamente como pesos en la construcción de indicadores compuestos.

El PCA se ha aplicado a dos casos de estudio: (i) la base de datos DEDUCE de indicadores de sostenibilidad de la costa y (ii) la base de datos del Atlas de Vulnerabilidad frente a derrames de hidrocarburos de Cantabria.

El proyecto DEDUCE (Martí et al., 2006) tenía como objetivo testar el sistema de indicadores de sostenibilidad de la costa construido por el Grupo de Trabajo sobre Datos e Indicadores de GIZC de la Comisión Europea. Este sistema, construido por expertos europeos en zonas costeras, está compuesto por siete objetivos de gestión, 27 indicadores y 61 variables. La construcción de este sistema no se basa en las técnicas de grupo de tipo sistémico propuesta por esta tesis; no obstante, este sistema se adapta perfectamente a un análisis cuantitativo para la identificación de las variables críticas para su uso como indicadores. Debido a lagunas en la base de datos y a la naturaleza de las variables se ha llevado a cabo una selección inicial y una imputación de datos faltantes utilizando técnicas de interpolación. El PCA se ha ejecutado finalmente sobre 25 variables (el 40 % de las variables iniciales) agrupadas por objetivo de gestión. Los resultados han permitido reducir de manera sustancial el número de variables que miden cada objetivo de gestión, reteniendo las variables que aportan la cantidad máxima de información en términos de varianza explicada. 11 variables han sido finalmente retenidas, representando una reducción del 56% con respecto a las variables iniciales.

El segundo caso de estudio corresponde a la aplicación del PCA a la base de datos del atlas de vulnerabilidad frente a derrames de hidrocarburos de Cantabria (AVDHC) (Fernández et al., 2007). En este caso la base de datos inicial estaba completa por lo que no ha sido necesario reducir el número de variables para el análisis o imputar los datos faltantes. La base de datos AVDHC se basa en un sistema de tres componentes (socio-económica, física y ecológica) que incluye un total de 14 indicadores, cada uno de los cuales está representado por una variable. La ejecución de la PCA ha comprobado la ortogonalidad del sistema de variables (las variables se comportan de manera completamente independiente), ya que cada una es representativa de una componente distinta.

En conclusión, un conjunto de variables seleccionadas por un grupo de expertos puede ocultar dependencias y relaciones invisibles a primera vista. Técnicas de análisis multivariante, en particular el PCA, permiten mostrar las relaciones y seleccionar las variables más importantes en términos de información aportada, para que se puedan utilizar para construir un sistema de indicadores constituido por variables significativas e independientes entre ellas.

6. Propuesta metodológica

Las distintas experiencias analizadas, las técnicas empleadas y desarrolladas y los experimentos realizados permiten definir un marco metodológico para la identificación de indicadores, orientados a problemas y ligados a contextos geográficos específicos, para la gestión integrada de las zonas costeras, que incluye esencialmente tres pasos:

1. Diagnóstico preliminar del problema e identificación de los actores costeros: a partir de una formulación inicial del problema, basada en el enfoque sistémico, los actores involucrados deben ser identificados de manera sistemática para poder recoger las múltiples perspectivas sobre las problemáticas del espacio costero de interés. Los mismos actores deben ser clasificados y seleccionados para participar sucesivamente en talleres participativos. Las bases teóricas y las técnicas de diagnóstico integrado e identificación y selección de actores se tratan en el capítulo 3 de la tesis.

2. Implicación de los actores y expertos para la construcción de un modelo del sistema compartido: a través de los talleres participativos, los actores y expertos costeros deben involucrarse en la identificación de los elementos más relevantes del sistema, llamadas “variables” por el pensamiento sistémico, y de las relaciones entre estos elementos, para construir un modelo de funcionamiento del sistema (ver capítulo 4 de la tesis).

3. Análisis del sistema: el sistema de variables, anteriormente construido mediante la combinación del conocimiento de los expertos con la percepción de los actores, debe ser analizado utilizando por un lado la información proporcionada en la construcción del modelo del sistema en términos de impacto y relevancia (ver capítulo 4), para luego aplicar técnicas estadísticas multivariantes como el análisis de componentes principales (PCA), siempre que los datos correspondientes sean disponibles. El PCA permite revelar las posibles correlaciones y dependencias que no han sido consideradas en las fases precedentes, identificando así las variables más relevantes en términos de varianza explicada y manteniendo la mayor cantidad posible de información (ver capítulo 5 de la tesis).

7. Conclusiones

El objetivo de la presente tesis ha sido el desarrollo de una metodología para la identificación de indicadores para las zonas costeras, para contextos geográficos específicos y orientados a problemas locales, en el ámbito del desarrollo sostenible. Este objetivo se ha alcanzado a través de la combinación de técnicas de participación pública, análisis sistémico y estadística multivariante en un marco metodológico aplicable a casos reales.

El análisis del estado del arte en técnicas GIZC ha revelado la existencia de lagunas en la aplicación de técnicas sistémicas y estadísticas para la identificación de indicadores para la gestión costera integrada. La revisión del estado del arte en otros ámbitos científicos como la ingeniería operacional, las ciencias del desarrollo sostenible, la macroeconomía y la medicina ha revelado el uso de avanzadas técnicas sistémicas y estadísticas avanzadas para analizar sistemas de variables e identificar o construir indicadores más o menos complejos: tales experiencia han servido de base e inspiración para esta tesis.

Varias experiencias en proyectos reales de GIZC han sido utilizadas para reforzar las hipótesis iniciales y para poder experimentar distintas técnicas, que permitan formular correctamente los problemas costeros con la ayuda de los actores locales y los expertos sectoriales. Los resultados de estas experiencias han aclarado que la implicación de actores locales y expertos sectoriales es fundamental para focalizar los problemas e llevar a cabo un diagnóstico correcto, pero que no es suficiente para poder identificar los indicadores óptimos que permitan medir el estado del sistema, cuantificar los efectos de las distintas alternativas y políticas y efectuar seguimientos a lo largo del tiempo.

El uso de técnicas de grupo basadas en la teoría del pensamiento sistémico se ha considerado como la opción más adecuada para focalizar los temas clave e identificar variables e indicadores para la gestión costera. En este sentido se han analizado las técnicas existentes y se han integrado con herramientas prácticas para capturar y analizar la información. Se ha demostrado que a través de estas técnicas es posible (i) identificar las variables del sistema y las posibles relaciones entre ellas, (ii) explicitar los modelos mentales de funcionamiento del sistema y agruparlos en un modelo mental compartido y (iii) analizar la contribución de los participantes en términos de relevancia de las distintas variables del sistema. Estas técnicas favorecen además el acercamiento de los puntos de vista de los participantes aumentando la comprensión y la construcción de consenso respecto a las problemáticas de interés y a sus posibles soluciones.

Los modelos sistémicos construidos con técnicas de grupo están esencialmente formados por variables conectadas entre ellas. Estos sistemas de variables pueden ser analizados, previa recolección de datos, a través de técnicas multivariantes como el PCA. Estas técnicas permiten analizar las posibles correlaciones e interdependencias entre variables, agrupándolas en componentes que recogen la mayor parte de la información en términos de varianza explicada. Las variables seleccionadas se pueden utilizar como indicadores críticos para el sistema o para construir índices compuestos. Los mismos resultados del análisis pueden ser utilizados para confirmar o refutar las relaciones hipotéticas identificadas en el modelado de grupo.

En conclusión, la combinación de técnicas de participación pública, análisis sistémico y estadística multivariante permite analizar sistemas costeros e identificar variables clave e indicadores críticos para medir el estado del sistema, cuantificar el efecto de distintas alternativas y políticas, y monitorizar el efecto de proyectos GIZC a varias escalas (obras litorales, planes regionales, estrategias nacionales). La construcción de un modelo de funcionamiento del sistema integrando el conocimiento de los expertos con la percepción de los actores locales representa un punto crítico y una oportunidad para incorporar información valiosa y generar una base de consenso inicial. El análisis de este sistema, incluyendo la importancia dada por los actores a las distintas componentes y los resultados de los análisis multivariantes, permite finalmente identificar las variables críticas del sistema para su uso como indicadores.

8. Futuras líneas de trabajo

Los resultados de la presente tesis han permitido identificar determinadas líneas de trabajo, consideradas importantes para fortalecer mi capacidad investigadora en distintos campos, con el claro objetivo de aplicar tales investigaciones en proyectos GIZC a distintas escalas y en diversos contextos geográficos.

En concreto, los modelos de funcionamiento del sistema costero basados en los diagramas causales representan la base para poder efectuar simulaciones dinámicas de distintos escenarios (ver por ejemplo: Smyth, 2000; Elrefaie, 2005; Khan, 2007; Kojiri, 2008; Zhang et al., 2008). Así, los diagramas causales pueden ser transformados en diagramas de flujo más complejos utilizando herramientas de dinámica de sistemas (Binder, 2008). Una ventaja importante de tales simulaciones dinámicas es que no necesitan bases de datos completas sino que bastarían suposiciones iniciales sobre los valores de las variables críticas (García, 2006).

En el caso que los datos sean disponibles, se deberían explorar y adaptar técnicas como el modelado de ecuaciones estructurales (*SEM, Structural Equation Modelling*) para evaluar las hipótesis de correlaciones causales entre variables (ver por ejemplo Pugesek et al., 2003; Hurlimann et al., 2008).

Por otro lado, la construcción de modelos del sistema basados en los paradigmas y técnicas de pensamiento sistémico, aplicados y desarrollados en esta tesis, se aplicaran en el proyecto MSICZMP, incluyendo más expertos y actores locales para ampliar la perspectiva en Egipto en la primavera de 2008.

CHAPTER 1 – INTRODUCTION

1.1 Problem description

Coastal areas are some of the most complex, diverse and valuable spaces on Earth. Physical processes such as waves, tides and currents, together with climate change, are constantly influencing the ecological processes such as biomass production and ecosystem biodiversity. The same physical processes constantly challenge the human population to find sustainable solutions to defend or adapt to it while protecting surrounding nature. Coastal zone resources are also very important for human economic and social activities such as energy production, transport of goods, fishing, leisure and tourism, making the coast an attraction for living: in 2001 over half the world's population lived within 200 km of the coastline and the rate of population growth in coastal areas is accelerating (UN, 2008). Population density and activities also generate conflicts between coastal uses, users and sectors. Institutions are therefore responsible for solving conflicts between nature and human activities using the most suitable and sustainable solutions from the natural, economic and social point of view.

Integrated Coastal Zone Management (ICZM) is regarded as an alternative for the sustainable management of coastal systems in the 21st century, using an approach which integrates the management of natural processes with the improvement of economic efficiency, involving stakeholders throughout the process. ICZM is therefore a complex, adaptive and participated process whose main objective is to improve the health of the coastal system as a whole by protecting sensitive ecosystems, maintaining flows in highly dynamic environments and adapting human uses, settlements and activities to complex changes.

ICZM theory calls for a systems approach to coastal zone management, which considers the effect of different policy options on the whole coastal system. The use of specific indicators is the way to measure the current condition of the system and the progress towards a desired state.

Broad and general sets of indicators are commonly proposed to measure the state of the coast and its progress towards sustainability. This approach is useful in comparing the state of ICZM implementation in different regions. On the other hand, while dealing with specific problems in particular coastal regions, problem-oriented indicators should be identified in order to measure the state of the coast with respect to problems which are not reflected in generic indicator sets.

In sum, the problem addressed by this thesis is the identification of site-specific and problem-oriented sets of indicators, to be used to determine baseline conditions and to monitor the effect of ICZM initiatives.

1.2 Research questions

The problem addressed in this thesis can be formulated with the following broad research question:

How can we identify the key variables of a coastal system in order to deliver effective indicators to be used in the management process?

If we limit this question to physical processes, answers are often available because complex models simulating the movement of water and sand have been developed and tested: the variables used in these models are indicators for operational or long-term management. As an example, we know that significant wave height H_s is a key variable for sediment transport, and that short-term or long-term changes in H_s can bring major changes to coastlines.

On the other hand, if we want to see a broader picture of the coastal system, we need to integrate more components which may be affected by changes (ecological, social, economic) creating a picture where interdependencies and causal relations between components are not deterministic or, at least, where science has not yet successfully solved the problem using a deterministic approach.

More integrated and holistic approaches should therefore be used to model the enlarged system and identify information for its integrated management.

The broad research problem has been divided into three specific research questions which drive the research in chapters 3, 4 and 5:

1. *How can we explore a coastal system in order to improve knowledge and understanding of the issues at stake?*

2. *How can we build a model of the system based on the contribution of experts and stakeholders?*

3. *How can we identify the variables which best describe the system in order to use them as coastal indicators?*

1.3 Structure of the thesis

This thesis is organized into four chapters.

- The first chapter, on the "State of the art", reviews coastal issues and coastal complexity, ICZM theory and practice, system sciences and their use in coastal management, and the use of indicators in different disciplines, including deeper insight into indicators for coastal management.

- The second chapter entitled "Exploration of coastal systems: integrating knowledge with perception", focuses on the complexity of coastal problems, on the use of policy analysis for problem structuring and on the role of coastal experts and coastal stakeholders in coastal profiling, and in the identification of coastal issues and indicators.

- The third chapter, entitled "Drafting models of coastal systems: a systems thinking approach" adapts systems thinking and group model building, two systems management techniques, to design coastal system models and identify key issues and variables with input from coastal experts and stakeholders.

- The fourth chapter of the thesis, entitled "Multivariate analysis of coastal systems: delivering critical indicators", introduces and applies a multivariate technique, the principal component analysis, to explore the system in terms of interdependencies between its variables, to identify the key variables of the system to be combined in a final set of indicators.

Throughout the text, examples, experiences and specific case studies are reported to improve the reader's understanding, test different techniques, and support the methodological approach proposed by this thesis.

1.4 A note on experiences, references and projects

This thesis is based on extended research in the field of ICZM and on lessons learnt in the last few years in different projects. The research encompasses review of major experiences in the international coastal science and coastal policy arena and has been conducted in parallel with projects which have contributed decisively to the results of this work.

The review of international experience in science and policy led to the exploration of different fields of knowledge which can contribute strongly to coastal management; these fields of knowledge include above all systems science, social science, business management, econometrics and multivariate statistics.

The objective of this review was to understand how these fields of knowledge can be integrated with other more traditional coastal disciplines such as coastal engineering, coastal ecosystems management and coastal geography.

Sustainable coastal management was always the theoretical paradigm in the background during work, while different practical projects have been fundamental to focus the research on reality, bridging the gap between science and management.

In the last few years, many authors have conducted theoretical and applied research on the integration of different fields of knowledge to solve coastal management issues as one of the challenges for science-driven management in the 21st century. These references have been considered throughout the research, representing a fundamental basis in support of this thesis.

Special acknowledgements must go to some of the authors, José Jiménez, Robert Kay, Adalberto Vallega, Jentje Van der Weide and Marc Van Koningsveld, who have contributed significantly to the integration of coastal science and engineering with management practices.

I have been involved in the last few years in different projects strictly related with Integrated Coastal Zone Management issues, some of which are reported in this thesis as case studies.

The following are the projects that have influenced this work, covering the areas of coastal policy, coastal engineering, education and training and international cooperation for coastal development:

- 2008 "CONSCIENCE: concepts and science for coastal erosion management" 6th FP specific targeted research project.

- 2007-2009 "Coastal restoration project for the beaches of Finale Ligure" Municipality of Finale Ligure, Italia.

- 2005-2009 "International cooperation for the development of an ICZM Plan in the coastal stretch between Matrouh and Sallum, Egypt" AECID, Spanish Agency for International Cooperation, Spanish Ministry of Foreign Affairs.

- 2005-2008 "National Strategy for Coastal Sustainability" Coastal Directorate General, Spanish Ministry of the Environment.

- 2005-2007 "Advanced Seminars on Integrated Coastal Zone Management in the Mediterranean" AECID, Spanish Agency for International Cooperation, Spanish Ministry of Foreign Affairs.

- 2005-2006 "National Stocktaking and Strategy for Integrated Coastal Zone Management in response to Recommendation 413/2002/EC" Coastal Directorate General, Spanish Ministry of the Environment.

- 2005-2008 "ENCORA: European Network on Coastal Research" 6th FP Coordination Action, European Union Research Programme.

- 2002-2004 "BEACHMED: beach restoration with marine sand deposits" Interreg3B project nº 2002-01-4.3-I-028, European Union Interregional Cooperation Programme.

CHAPTER 2 – STATE OF THE ART

2.1 Introduction

The purpose of this chapter is to revise the state of the art in ICZM, systems sciences and the development of indicators, in order to identify knowledge gaps and to set the basis for the development of a systems approach to identify problem-oriented sets of indicators for coastal management.

- Section 2.2 presents the coastal zone as a complex socio-environmental system, and introduces ICZM as a way to deal with problems in the coastal zone, through the revision of its development, focusing on Europe, the Mediterranean region and Spain.

- Section 2.3 introduces systems sciences, including its sub-disciplines, emphasizing the potentials of systems thinking (ST) and systems dynamics (SD). The most relevant experiences in the use of the systems approach in various disciplines, including ICZM, are then analyzed, in order to identify the most suitable approach to build a model for a given coastal system.

- Section 2.4 provides a revision of the use of indicators in different disciplines, from econometrics to sustainability sciences and ICZM, focusing on the models used to identify indicators and on the analyses carried out to validate the indicators system.

2.2 The coastal zone and its management

2.2.1 The coastal zone

The coastal zone is a highly dynamic and fragile environment, concentrating important human activities and strategic economic sectors. The peculiarity of this zone lies in the natural processes and human activities which are strictly related with the coastal environment, which are not found in other places.

Many different authors have dedicated much effort to the characterization of the coastal zone and to the description of its importance in terms of natural and human processes (Cicin-Sain et al., 1998; Vallega, 1999; Barragán, 2004; Kay et al., 2005). According to Kay (Kay et al., 2005), the coast is unique because it is where land and ocean meet, and the contrast between land and ocean can be dramatic, where ocean swells crash against rock cliffs, or more gradual, where tides flows over marshes.

The interaction between the marine and terrestrial environments make the coast unique and uniquely challenging to manage.

The Santander bay is an emblematic example, as important physical processes, fragile ecosystems, and human pressures meet in a relatively limited space (figure 2.1).

Figure 2.1. Santander bay, Cantabria, Spain: a complex socio-environmental system in the coastal zone, characterized by multiple uses in a highly dynamic environment.

Coastal diversity and productivity

The importance of the coastal zone can be described in terms of coastal diversity and coastal productivity.

As an analogy with the concept of diversity in ecology, coastal diversity can be seen as the number of types of processes with respect to the total number of processes, where processes are either natural or human. The importance of the coastal zone can also be analyzed in terms of coastal productivity, in an analogy with the concept of productivity in ecology, as the total quantity of biomass production. Coastal productivity can be seen as the sum of the total biomass production, including humans, and the total value of human activities in socio-economic terms. The formalization of the concepts of coastal diversity and coastal productivity are not part of the present thesis, but it has been considered as a good and innovative way to regard the coastal system as a whole.

Coastal complexity

The coastal zone can be considered as a complex socio-environmental system.

Complexity in a given system arises when its components have many relations with the others, and their identification is not straightforward. The challenge in the study of complex systems is the identification of organizational patterns and emergent properties. In the coastal zone, complexity is associated with physical processes, such as waves, tides, currents and sediment transport. Complexity is also associated with ecological processes in a zone of high level of biodiversity and productivity. Complexity also arises in coastal socio-economic processes, when productive activities interact with human uses and the surrounding environment, especially in densely populated coastal zones.

Coastal boundaries

The spatial boundaries of the coastal zone vary depending on the scope of the problem and on the possible management solutions.

If we start thinking about the coast as a complex system, one of the basic ideas is to extend these boundaries to the limit of the processes considered in a system's model. A common error, in past and present coastal management, is to limit problem solving in space and time: this approach can bring unintended consequences in the long term, which can also affect short term decisions.

Different authors have discussed the problem of the definition of boundaries for the coastal zone. Kay (Kay, 2005) states that there are parts of the coastal environment which clearly have strong interactions between land and ocean, including beaches and coastal marshes, while other parts are more distant from the coast (inland or seaward), while still play a role in shaping the system. One of the most important parts is clearly the rivers that bring freshwater and sediments to the coastal environment, for which the inland limit of the coastal zone is the river catchment.

A significant definition is given by Ketchum (Ketchum, 1972), who considers the coast as the band of dry land and of adjacent ocean space (water and submerged land) in which terrestrial processes and land uses directly affect ocean processes and uses and vice-versa.

Human activities which are correlated with the coastal zone are also criteria for boundaries setting, such as navigation, coastal tourism, agriculture, etc. Nonetheless the coastal zone is also identified or affected by administrative boundaries such as regions, municipalities, natural protected areas, etc. which can be clearly associated with coastal processes. The degree of interaction between land and sea has been tentatively formalized by some authors, who proposed “coastality” or “coastalness” as a quantifiable parameter (Kiousopulos, 2004; Kay et al., 2005). Figure 2.2 illustrate these concepts.

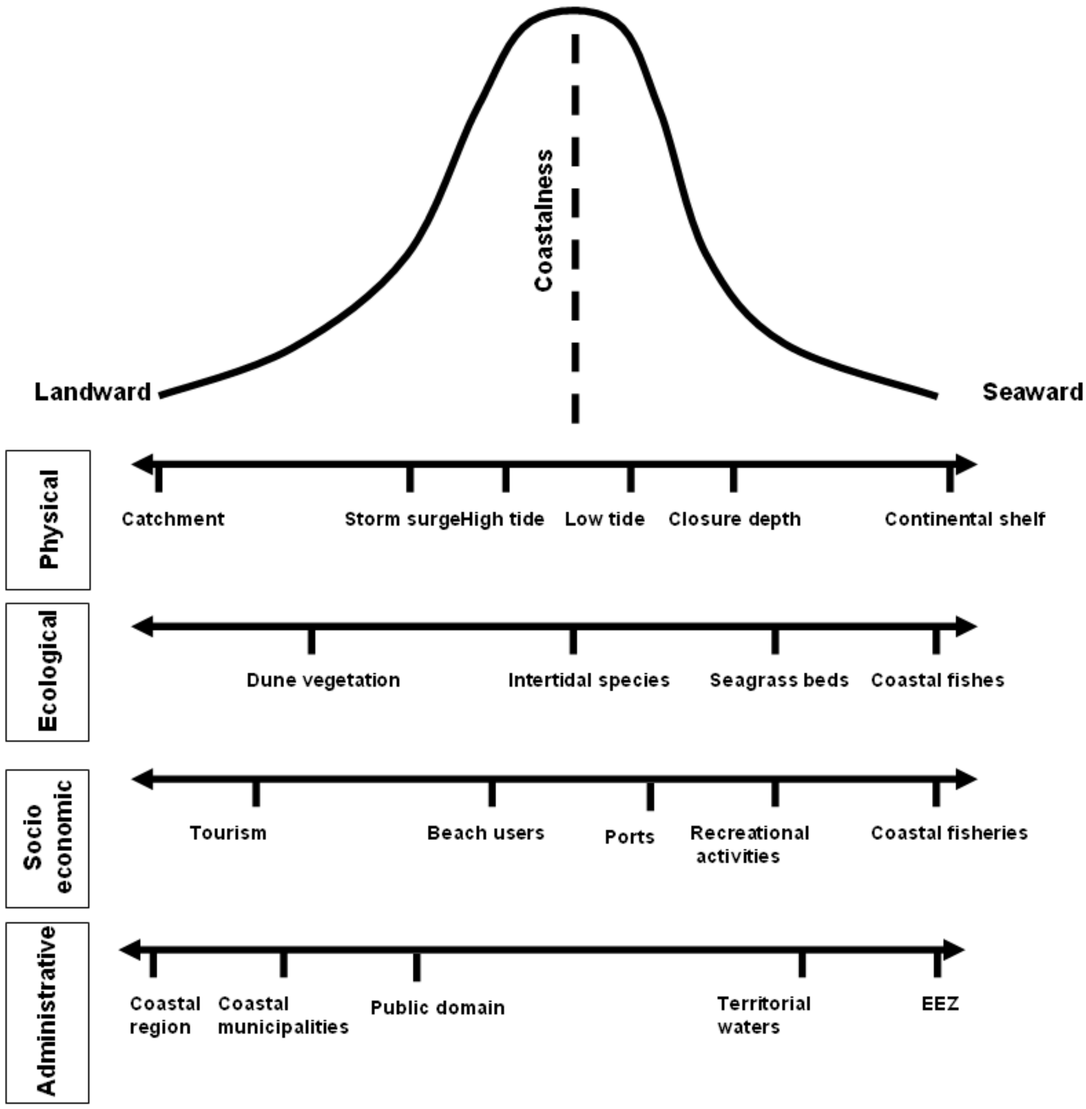


Figure 2.2. The degree of "coastalness", based on different criteria (adapted from Kay et al., 2005).

While using a systems approach to understand complex coastal problems, the boundaries of the system are shifting, depending on the boundaries of the proposed model. This means that it is not possible to set definite boundaries for the system until the relevant processes are identified and analyzed. The identification of relevant processes is strictly related with the identification of the key issues which set the bases of the system's model.

Coastal issues

A broad vision of the coastal system should bring together the multiple issues at stake.

Many authors have tried to treat coastal issues in a systematic way. Probably the most significant example in this sense is the work of Clark, in the Coastal Zone Management Handbook, where he revises all the coastal issues that can be considered relevant for coastal management (Clark, 1996). A revision of important coastal issues has also been carried out by Vallega, focusing more on coastal uses and the conflicts which arise from their interaction (Vallega, 1999). Kay dedicates a special chapter of his renowned book, Coastal Planning and Management (Kay et al., 2005), to identify the most common issues of the coastal zone, with many different examples from all over the world. The following figure (figure 2.3) randomly reports some of the most common coastal issues faced by ICZM. In the figure, possible connections are not highlighted, but underlying relationships and causalities clearly exist.

Figure 2.3. Some of the most common coastal issues faced by ICZM. Underlying complex relations determine the systems behavior.

2.2.2 ICZM principles

Integrated Coastal Zone Management (ICZM) is a process for the management of the coast using an integrated approach, regarding all aspects of the coastal zone, including geographical and political boundaries, in an attempt to achieve sustainability.

Key concepts and guidelines for ICZM are widely reported in the literature (Clark, 1996; Cicin-Sain et al., 1998; Vallega, 1999; Chua, 2006; Kay et al., 2005), and the common points to all of them are the following:

1. Triggering factors for ICZM: the need for Integrated Coastal Zone Management arises when relations between coastal-maritime sectors generate social and economic conflicts and negatively affect the surrounding environment.

2. Integration of actors: ICZM processes are based on the construction of consensus around the recognition of coastal problems and the identification of possible solutions. Actors, belonging to different sectors of the society or the economy, must be involved from the beginning of the process, using public participation techniques.

3. Coastal system: the coast is a complex system where strong physical processes, fragile ecosystems and human pressures meet. A good knowledge of processes and relations between the coastal system's components is fundamental to implement ICZM.

4. Spatial dimensions: the coastal zone is a broad fringe where borders are identified either by physical processes, ecological flows or human boundaries. A correct definition of the spatial dimension of the problem can avoid unintended consequences while implementing alternative solutions.

5. Data and information management: The coastal system can only be managed if data and information about the system is available and collected. Specific problems can only be described by specific information, either qualitative or quantitative. Improvements of the system performance should be measured and monitored over time.

More specifically, In Europe, the Recommendation 413/2002/EC on ICZM provides the Member states with eight specific principles for ICZM implementation (table 2.1):

Item	Description
Systems approach	Broad overall perspective (thematic and geographic) which will taking into account the interdependence and disparity of natural systems and human activities with an impact on coastal areas.
Sustainability	A long-term perspective which will take into account the precautionary principle and the needs of present and future generations.
Knowledge development	Adaptive management during a gradual process which will facilitate adjustment as problems and knowledge develop. This implies the need for a sound scientific basis concerning the evolution of the coastal zone.
Local specificity	Local specificity and the great diversity of European coastal zones, which will make it possible to respond to their practical needs with specific solutions and flexible measures.
Working with nature	Working with natural processes and respecting the carrying capacity of ecosystems, which will make human activities more environmentally friendly, socially responsible and economically sound in the long run.
Public participation	involving all the parties concerned(economic and social partners, the organizations representing coastal zone residents, non-governmental organizations and the business sector) in the management process, for example by means of agreements and based on shared responsibility.
Institutional integration	Support and involvement of relevant administrative bodies at national, regional and local level between which appropriate links should be established or maintained with the aim of improved coordination of the various existing policies. Partnership with and between regional and local authorities should apply when appropriate.
Plans integration	Use of a combination of instruments designed to facilitate coherence between sectoral policy objectives and coherence between planning and management.

Table 2.1. ICZM principles of the Recommendation 413/2002/EC (from EC, 2002).

2.2.3 The evolution of ICZM

The concept of ICZM was born during the United Nation Conference on Environment and Development (UNCED) (UN, 1992), also known as the Earth Summit, held in Rio de Janeiro in 1992, sustainable development being the central issue addressed during the summit. Agenda 21, one of the results of the summit, is a programme of actions for the environment in the 21st century. Chapter 17 of this broad agenda focuses on the protection of the world's coasts and oceans, and introduces concepts, objectives, activities and means for the implementation of integrated management and sustainable development of coastal and marine areas, including the Exclusive Economic Zones (EEZ).

Vallega (Vallega, 1999) provides an interesting revision of the evolution of ICZM before the UNCED was launched, up to 1999, through the identification of the events which represent milestones in ICZM history.

One of them, the US Coastal Zone Management Act (CZMA) of 1972, deserve greater attention, being the oldest and probably one of the most effective existing coastal policy instruments.

The CZMA overall objective is to "preserve, protect, develop, and where possible, to restore or enhance the resources of the (US) Nation's coastal zone for this and future generations."

The CZMA established a framework for a federal and state coastal management partnership to balance economic growth with coastal protection. The National Coastal Management Program (NCMP) and the National Estuarine Research Reserve System (NERRS) work together to achieve the goals of the CZMA. Both programmes are relevant, but the NCMP better fits into ICZM broad principles. The NCMP is a voluntary partnership between coastal states and the federal government, where NOAA's Office for Ocean and Coastal Resources Management works with coastal states to develop comprehensive coastal management programs tailored to the unique resources, conditions, and needs of each state. Although the nature and structure of coastal management programs vary from state to state, they are guided by the following national goals:

1. Protect and restore significant coastal resources.

2. Prevent, reduce, or remediate polluted runoff to coastal waters.

3. Improve public access to the coast.

4. Minimize the loss of life and property in coastal hazard areas.

5. Promote sustainable growth in coastal communities.

6. Provide for priority water-dependent uses.

7. Improve government coordination and decision-making.

The CZMA calls for the 34 participating states to implement coastal planning and management programs and for the federal government to provide program oversight, policy guidance, technical, assistance, and financial resources to assist state programs. Federal funding to the states is distributed according to a formula combining the coastal population with the length of the coastline.

The CZMA can be considered as a mature and successful instrument for ICZM, but the need for a comprehensive system to measure programme performance was only faced in 2001, 30 years after the CZMA approval, through the proposal of a National Coastal Management Performance Measurement System (NCMPMS), a mechanism to quantify the national impact of the CZMA by tracking and aggregating indicators of the effectiveness of the CZMA programs. The set of indicator is reported in table 2.5 of the present chapter.

2.2.4 European perspectives in ICZM

In the early 90's the European institutions, in compliance with the results obtained by international initiatives, such as the UNCED of 1992 (UN, 1992), recognized the importance of Integrated Coastal Zone Management as a way to reach sustainable development in the coastal zone.

The European Commission defines ICZM as a dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones, covering the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. Following this definition, ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, in the long-term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics.

"Integrated" in ICZM refers to the integration of objectives and also to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors, and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space.

Many pilot projects and programmes have been promoted by the EC, first of all the Demonstration Programme on ICZM operated in the late '90s (EC, 1999), which set the basis for the incorporation of ICZM principles into the European legal system. The Recommendation 413/2002/EC adopted by the European Commission (EC, 2002) represents the latest initiative to define a common coastal policy for the EU, and its outputs were delivered in 2006. This Recommendation, based on the experiences and outputs of the Demonstration Programme, aimed to establish a common framework for the implementation of ICZM in the Member States, asking for: (i) a national stocktaking of actors, laws and institutions concerned with the coastal zone and (ii) a national strategy for ICZM with the instruments for its implementation.

Other coastal-relevant European requirements exist, including the Habitat Directive, the Water Framework Directive, The Marine Strategy Directive, the Directive on Flood Risks, and the INSPIRE directive on spatial data management. All of them address issues that are strictly related with ICZM, but no ICZM Directive exists, and is probably not going to exist in the future: ICZM is now considered in Brussels as one component the EU Integrated Maritime Policy (EC, 2009).

A comprehensive analysis of the response of the Member States to the recommendation was carried out in 2006 (Rupprecht Consult et al., 2006), resulting in 5 strategic recommendations and specific actions to be carried out in the future, in order to implement ICZM all over the EU. Strategic recommendations and specific actions are reported in the following table (table 2.2).

Strategic recommendations	
1	Strengthen the European dimension of ICZM based on Regional Seas approach.
2	Raise the profile of ICZM and enhance its integration with sectoral policies.
3	Elaborate the strategic approach of ICZM – oriented to a balanced ecologic, social, economic and cultural development.
4	Address major long-term risks: vulnerability and disasters and climate change.

Table 2.2. Strategic recommendations based on the analysis of the response to the ICZM recommendation (from Rupprecht Consult et al., 2006).

The UNEP/MAP Protocol on ICZM, recently approved by the European Council (EC, 2009) is currently the most important initiative affecting the Mediterranean side of the European coast, and is supposed to drive research and projects in the near future.

2.2.5 Developing a common framework for ICZM in the Mediterranean

In 1975, 16 Mediterranean countries and the European Community adopted the Mediterranean Action Plan (MAP), the first-ever Regional Seas Programme under UNEP's umbrella. In 1976 these Contracting Parties adopted the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention). Seven Protocols addressing specific aspects of Mediterranean environmental conservation complete the MAP legal framework, one of them being The Protocol on Integrated Coastal Zone Management, signed in Madrid in January 2008. A further push to the MAP was recently given by the “Union for the Mediterranean”, a French proposal based on the existing Barcelona Process of 1995, designed to enhance multilateral relations, increase co-ownership of the process, set governance on the principle of equal footing and translate it into concrete projects with higher visibility (UNEP/MAP, 2008).

The Protocol on ICZM of the Barcelona Convention aims to establish a common framework for the integrated management of the Mediterranean coastal zone, placing special emphasis on the implementation of sustainability principles in economic activities, ecosystem management, cultural heritage, public participation, education and international cooperation.

The Protocol encourages all Parties to define a regional framework for the development of a Mediterranean Strategy on ICZM. This Strategy should be implemented through regional action plans and national coastal strategies together with coastal plans and programmes. Each Party is consequently asked to formulate a National Strategy following the principles of ICZM: long-term holistic view, maritime-terrestrial knowledge integration, ecosystem approach, public participation, administrative coordination, public access to the coast, sectoral policies integration, spatial planning, sustainable use of coastal resources, etc. According to the Protocol, this approach will allow the countries to better manage their coastal zones, as well as to deal with the emerging coastal environmental challenges, such as climate change.

The Protocol suggests some instruments for the implementation of ICZM, such as economic, financial and fiscal measures, monitoring tools and networks, environmental impact assessments, land policies and awareness-raising, training, education and research. Additionally, it highlights the need for international cooperation in terms of ICZM to Parties requiring such assistance, as well as exchanging of information of interest.

More specifically, the Protocol encourages the Parties to define appropriate indicators in order to evaluate the effectiveness of integrated coastal zone management strategies, plans and programmes, as well as the progress of implementation of the Protocol (UNEP, 2008).

2.2.6 Notes on ICZM in Spain

The present section represents a short summary of ICZM experiences in Spain, where much work of this thesis was developed. Further details can be found in Sanò et al., 2009.

The Spanish coasts are of strategic importance from an environmental, economic and social point of view in the country's overall balance. Spain's 6600 km of coast (EC, 2004) are distributed between 5 coastal macro-regions (the Mediterranean coast, the Balearic Islands, the Atlantic, the Canary Islands and the North Coast) characterized by an exceptional diversity in terms of climate and ecosystems. Each macro-region can be considered slightly or very different from the other, due to its environmental conditions, which depend on a combination of variables related to geomorphology, coastal dynamics, climate and ecology, generating unique landscape and environmental processes. Natural conditions drive the distribution of the activities along the coast: tourism, industries, fisheries and agriculture can be seen as the main activities, with fisheries and industrial activities mostly concentrated in the North coast and tourism and agriculture in the Mediterranean and the islands.

Human pressure in the Spanish coastal zone is high. 10 of the 17 Spanish regions are on the coast, and their coastal municipalities, representing 7 % of the total area of Spain, host nearly 44% percent of the Spanish population (INE, 2005). Tourism, responsible for the 11% of the GDP of Spain, is a strategic sector in the Spanish economy driving most of the issues of the coastal zone, mainly those of the building sector, one of the main threats to the coastal system equilibria. Most of the current problems are concentrated in the Mediterranean coast, the Balearic Islands and the Canary Islands. Intensive fishing and agriculture also contribute to the degradation and overexploitation of coastal resources and together they reflect the short-term vision and lack of integration in the management of the coastal zone (Barragán, 2003; Suárez de Vivero et al., 2005; Greenpeace, 2005).

The Spanish coastal zone is managed by the State, the Regional Government of the Autonomous Communities and the coastal Municipalities, with a complex distribution of competences. The Coastal Directorate General of the Ministry of the Environment (DGC-MMA), is in charge of the management of the Maritime Terrestrial Public Domain (MTPD), defined by the Spanish Constitution and regulated by the Coastal Act of 1988. Other authorities at the State level are responsible for the management of sectoral activities in the MTPD, such as maritime transportation and State ports, fisheries in territorial waters, oil, gas and energy exploitation. Regional main competences include physical planning, regional ports, fisheries and aquaculture in internal waters and the quality of coastal waters. Finally, local administration is represented by coastal municipalities, whose main responsibilities are related to urban planning and various local services for the use and accessibility of public beaches. In any case urban plans are subject to the approval of the regional planning authorities, following a hierarchical cascade structure.

Most of the Spanish Autonomous Communities have launched specific initiatives for ICZM and some of them are legally bounding (Gobierno de Cantabria, 2004; Gobierno del Principado de Asturias, 2005; Generalitat de Catalunya, 2006; Junta de Andalucía, 2007), The Strategy for Coastal Sustainability (further referred to as SCS) promoted by the Ministry of the Environment, is currently the main initiative at the Spanish national level to implement ICZM. The purpose of the initiative is the promotion and implementation of coastal sustainability principles at the national level, beginning with the Mediterranean coast and the islands. The overall strategic framework of the SCS is summarized in Table 2.3 (Ministerio de Medio Ambiente, 2006). Further information concerning the public participation process is provided in section 3.4.

Strategic objective	Specific objective
1. Sustainable models of coastal development and sustainable use of coastal resources	1.1 Sustainable management of coastal erosion processes
	1.2 Protection and restoration of coastal ecosystems
	1.3 Sustainable use of natural resources in the coastal zone
	1.4 Control of the risk of natural hazards and environmental incidents
	1.5 Improvement of the public use and accessibility to the coast
	1.6 Protection and promotion of the coastal cultural heritage
2. Improvement of the decision making mechanism for the integrated management of the coastal zone	2.1 Integration of knowledge and information in the decision making process
	2.2 Vertical and horizontal coordination between administrative levels
	2.3 Public participation in the decision making process
	2.4 Securing financial resources for ICZM

Table 2.3. The strategic and specific objective of the Spanish Strategy for Coastal Sustainability (from Ministerio de Medio Ambiente, 2006).

2.3 The Systems approach

A systems approach to coastal zone management has been theorized by different authors, but few practical examples of its implementation exist at yet.

Based on philosophical paradigms and a geographical perspective, Vallega (Vallega, 1992; Vallega, 1999) proposed a complex systems approach to the management of the coastal zone. At the same time Van der Weide (Van der Weide, 1993) proposed a systems view of coastal management, integrating nature and society, from the coastal engineering perspective of the Delft tradition. A further effort to apply systems theory to ICZM has been done by Kay (Kay et al., 2003; Kay et al., 2005), stressing the importance of the application of management cybernetics to goal-oriented systems, including ICZM.

Systems sciences in a broad sense have been applied to study, understand, model or solve complex systems in many different fields. Some recent examples include fisheries (Bald et al., 2006; Utne, 2006) water resources (Smyth, 2000; Khan, 2007; Kojiri 2008; Zhang et al., 2008) and health (Newman, 2003; Patel, 2008). An extended literature on the relation between sustainability and systems sciences is also available (Kelly, 1998; Ronchi et al., 2002; Chan et al., 2004; Shi et al. 2004; Reed et al., 2005; Alvarez-Arenas, 2006; Hjorth et al., 2006). However, the major developments in the systems approach have been driven by the business & management sciences, operations research and industrial engineering. In this sense, this thesis is partly inspired by the systems thinking approach, developed at the MIT Sloan School of Management by Forrester, Senge and Sterman (Forrester, 1968; Senge, 1990; Sterman, 2000).

2.3.1 Systems sciences

An overview of the systems sciences is fundamental to understand how a systems approach can be used in coastal management practice.

Systems sciences comprise different interdisciplinary fields of science, which study the nature of complex systems in nature, society, and science. System sciences include all the disciplines which have been developed to model complex systems behavior for over 50 years of theoretical and applied research. Under the name systems sciences the following disciplines and approaches should be included: systems theory, cybernetics, operations research, complex systems, complex adaptive systems, systems thinking, and systems dynamics. A deeper classification and analysis of the evolution of systems sciences is not the objective of this thesis and other authors have carried out extended works in this field (see for example: Jackson, 2000). The underlying paradigms and concepts of the systems approach are examined as follows.

Holism

Holism is the fundamental paradigm which lies below the systems approach. Holism is the idea that all the properties of a given system (biological, chemical, social, economic, mental, etc.) cannot be determined or explained by its components alone. Instead, the system as a whole determines to great extent how the parts behave.

The general principle of holism was concisely summarized by Aristotle in the Metaphysics, in around 350 BC, stating that "The whole is more than the sum of its parts."

The holistic approach in science emphasizes the study of complex systems. This practice is in contrast to a reductionist approach which aims to understand systems by dividing them into their smallest possible or discernible elements and understanding their elemental properties each one on its own.

Descartes, one of the fathers of modern philosophy, was a strong supporter of reductionism, through the division of, as he said, "each of the difficulties that I was examining into as many parts as might be possible and necessary in order to best solve it".

The success of science in producing knowledge and of its associated technologies in transforming our world demonstrated that reductionism is the right approach to solve certain types of technological problems (Jackson, 2000). On the other hand, when we are faced with complex real-world problems of societies and organization, a reductionist approach can loose many emergent properties of the system as a whole. Holism and reductionism should be therefore regarded as complementary viewpoints, in which case they both would be needed to get a proper account of a given system.

System

A system is a set of interacting or interdependent entities (components), real or abstract, forming an integrated whole. There are both natural and man-made (designed) systems.

Man-made systems normally have a certain purpose, a set of objectives. They are "designed to work as a coherent entity". Natural systems may not have an apparent objective but they are sustainable, efficient and resilient.

Systems are frequently so complex that their behavior appears new or emergent: it cannot be deduced from the properties of its components alone.

Complex system

A complex system is composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) which are not discernible from the properties of the individual parts. Examples of complex systems include human economies, climate, nervous systems, cells and living things, including human beings, as well as modern energy or telecommunication infrastructures. Indeed, many systems of interest to humans are complex systems. Complex systems are studied by many areas of natural science, mathematics, and social science. Fields that specialize in the interdisciplinary study of complex systems include systems theory, systems ecology, complex adaptive systems, cybernetics, systems thinking and systems dynamics.

Systems theory

Systems theory as an area of study predominantly refers to the science of systems that resulted from Bertalanffy's General System Theory (GST) (Von Bertalannfy, 1968). The theorist defined general principles of open systems and its relation with thermodynamics principles, emphasizing the limitations of conventional models. He ascribed applications to biology and the possibilities for the development of cybernetics.

Systems ecology

Systems ecology, a sub-discipline of the systems sciences, is an interdisciplinary field of ecology, taking a holistic approach to the study of ecological systems. Systems ecology can be seen as an application of the general systems theory to ecology. Central to the systems ecology approach is the idea that an ecosystem is a complex system exhibiting emergent properties. Systems ecology focuses on interactions and transactions within and between biological and ecological systems, and is especially concerned with the way the functioning of ecosystems can be influenced by human interventions. It uses and extends concepts from thermodynamics and develops other macroscopic descriptions of complex systems. A central feature of systems ecology is the general application of the principles of energetics to all systems at any scale. Odum, the father of systems ecology, approaches systems modeling using the principles of thermodynamics and energetics (Odum, 1983) using a dedicated language as a tool for making systems diagrams and flow charts (see figure 2.4).

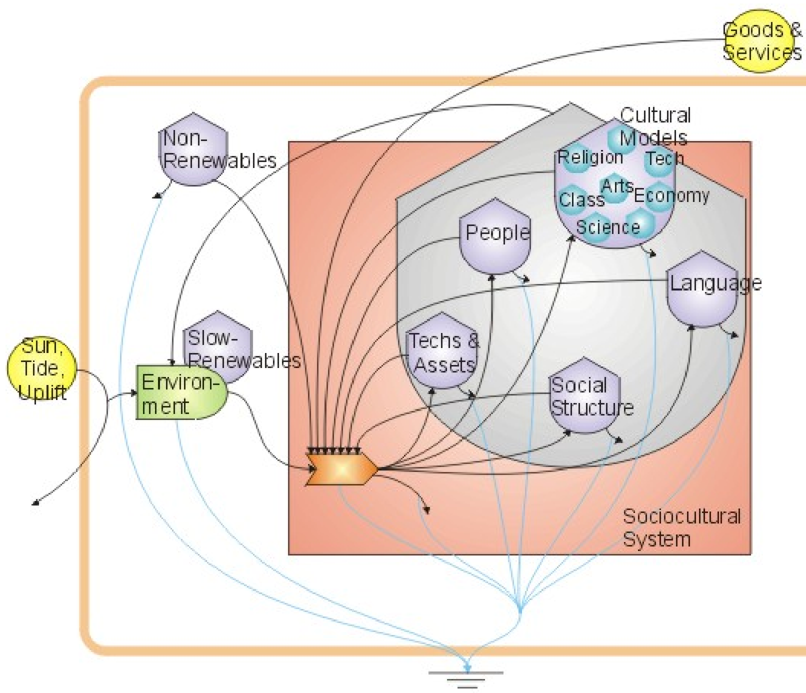


Figure 2.4. A socio-environmental system based on Odum's "Eneregese" language for system's modeling (from Abel, 2003).

Complex adaptive systems

Another important field of knowledge, which is part of the systems sciences, is represented by the complex adaptive systems (CAS). Holland (Holland, 1975) established the theory of CAS and defines it as a dynamic network of many agents functioning in parallel, constantly acting and reacting to what the other agents are doing: CAS are complex, because they are diverse and made up of multiple interconnected elements and adaptive, because they have the capacity to change and learn from experience. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents (see figure 2.5).

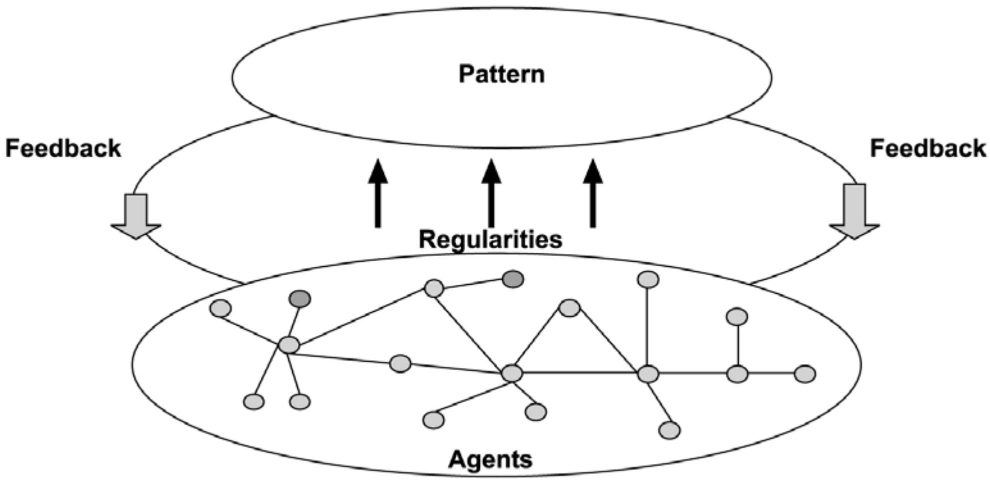


Figure 2.5. A simple example of Complex Adaptive System(CAS) (from www.trojanmice.com*)*

Cybernetics

Systems theory and complexity are strictly related with the development of cybernetics, which is the interdisciplinary study of the structure of complex systems, especially communication processes, control mechanisms and feedback principles. Formally introduced by Wiener in 1948 (Wiener, 1948), cybernetics was then applied to many fields of knowledge such as artificial intelligence, systems engineering, social and management science. An early and very interesting work in the use the use of systems sciences and cybernetics principles in spatial planning was carried out by Mc Loughlin (Mc Loughlin, 1969) who simulated urban system behavior using mathematical models.

More specifically, Management cybernetics is the concrete application of natural cybernetic laws to all types of organizations and institutions created by human beings, and to the interactions within and between them. Stafford Beer, the father of management cybernetics, developed the Viable System Model (VSM), to diagnose the faults in any existing organizational system (Espinosa et al., 2008). His ideas and his work had a strong influence in industrial organization, management and politics during the '70s when he was involved in large scale projects such as the Cybersin project in Allende's Chile (Medina, 2006).

Systems thinking and systems dynamics

Systems thinking (ST) is a framework for systems practice, a way of thinking holistically about problems while focusing on the components and relations of complex systems. Systems dynamics (SD) can be considered a part of the systems thinking processes when quantitative variables and numerical simulations are carried out to analyze the structure and behavior of a given system.

The origins of systems dynamics are older than those of systems thinking, the one having been first developed by Forrester in the '60s (Forrester, 1968) and the latter formalized by Checkland during the '80s (Checkland, 1981) and by Senge in the early '90s (Senge, 1990) Despite the fact that over 30 years have passed, the debate about what is systems thinking is and what it is not is still a hot topic (Cabrera et al., 2008).

Systems thinking and systems dynamics are strictly related disciplines.

Systems dynamics started from the idea that models normally used in engineering to test complex processes could be used to improve the understanding of complex social systems: systems simulations could improve social systems the same way as feedback models and cybernetics were improving industrial processes. The evolution in the field, signed by large-scale modeling experiences such as the ones promoted by the Club of Rome (Meadows, 1972), was a starting point for the development of softer approaches which lead to the formalization of systems thinking.

Systems thinking is an approach to problem-solving which considers the problems as part of the system, not as side-effects of policy options. System thinkers analyze complex systems through a systematic problem exploration, in order to overcome limitations of mental models of reality.

Combining systems thinking and systems dynamics is a way to support and confirm models through simulation and help to identify key variables, using sensitivity analysis of the model.

The ST/SD approach was recently used in research projects such as INSURE (Alvarez-Arena, 2006) and SPICOSA (SPICOSA WP3, 2007), being the latter strictly related with ICZM.

2.3.2 Systems approaches to ICZM

The basic ideas behind the use of the systems approach are well introduced by Sterman in the book "Business Dynamics" (Sterman, 2000), where systems thinking and systems dynamics are mainly applied to business management and policy analysis. An adaptation to coastal zone management is the following:

"Accelerating coastal changes in terms of environmental problems, social needs, economic development and technological solutions challenge coastal managers to learn and understand at increasing rates, while complexity of the coastal system is growing. Many of the problems faced by coastal managers arise as unanticipated side effects of their past decisions and actions. Therefore, effective decision making and learning, in a world of growing dynamic complexity, requires coastal managers to become systems thinkers: to expand the boundaries of their mental models and develop tools to understand how the structure of the coastal system creates its behavior".

Vallega (Vallega, 1999) gave a strong theoretical contribution to the application of the systems approach to ICZM. Following its definitions, the coastal system is a special system, because it is bi-modular: one module is the coastal ecosystem, comprising all the natural processes; the other module is the coastal community, comprising social and economic process. The coastal system, in Vallega definition, is regarded as a complex system, as it cannot be described exhaustively but only represented in an holistic way, through the use of models, i.e. the interface between reality and what we have in our minds (the so-called mental models, a systems thinking paradigm).

Van der Wiede further explored the potential of the systems approach to ICZM (Van der Weide, 1993), inspired by the General Systems Theory of Von Bertalannfy (Von Bertalannfy, 1968) and by the ideas of Forrester in Systems dynamics (Forrester, 1968). Its model for the coastal system (see figure 2.6) is based on the interaction of the natural and socio-economic sub-systems and three components: the natural system, functions and infrastructure. According to Van der Weide, the small circle in the centre, with its strategic position in between the three major systems represents the crucial role of ICZM, where relevant information lines come together and where strategies for sustainable development are prepared, based on a coherent knowledge basis, information systems, and policy analysis.

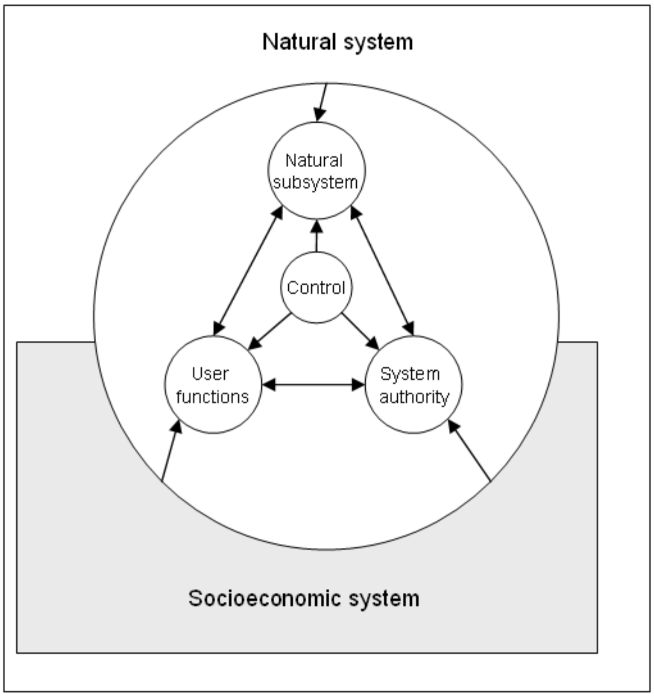


Figure 2.6. The system view of coastal management (adapted from Van der Weide, 1993).

Van Koningsveld (Van Koningsveld, 2003), using Van der Weide's model, modified the previous system adding system control through an institutional sub-system. This sub-system contains all the enabling mechanisms and instruments required for proper management. The connection between policy and the actual system's behavior is modeled using an ideal frame of reference (see figure 2.7) which connects policy (control) with science (the system).

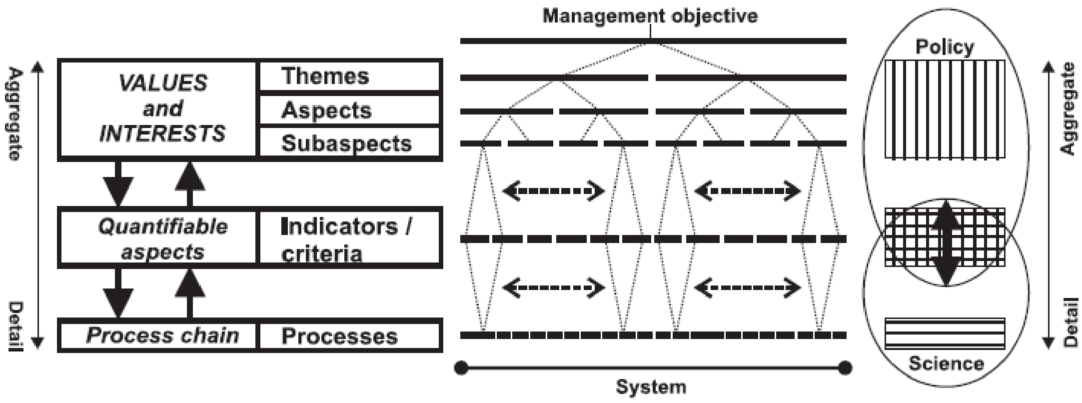


Figure 2.7. Bridging the gap between science and policy (from Van Koningsveld, 2003).

The issue of control of the coastal system is strictly related with cybernetics. Kay (Kay, et al. 2003; Kay et al., 2005) explores the relation between cybernetics and ICZM. In its analysis, cybernetics addresses the internal components that mediate the relation of the system with the environment, and its capacity to change in response to it. Institutional arrangements in the cybernetics sense can therefore be seen as control mechanisms for the systems they are intended to influence. Kay also highlights the importance of the contribution that other systems approaches can give to coastal management, such as Checkland's SSM (Soft Systems Methodology) and Senge's systems thinking.

One example of application of SSM to ICZM is reported in Vella (Vella, 2002): in this case SSM was applied to the CAMP Malta under the Mediterranean Action Plan of the Barcelona Convention. The SSM applied to the CAMP Malta was based on collaborative enquiry to key stakeholder that drove to the identification of a suite of sustainability indicators.

The review of the systems approach to the coastal zone and its management shows that efforts have been made to use systems approach to understand, design and model complex relation between coastal components.

The use of systems thinking in its broader sense, comprising problem structuring, causal loop diagramming and dynamic models has been found to be a common practice in field such as business management, policy analysis, health, sustainability and water management, but few examples exit about its adaptation to the coastal management field. One of these examples is the EU funded SPICOSA project the most recent, although no publications are yet available. On the other hand water management, a field akin to coastal management, has lately developed some interesting literature about the use of systems thinking and systems dynamics concepts, language, and tools as a framework to solve water related issues (Smyth, 2000, Khan, 2007; Kojiri, 2008; Zhang et al., 2008): these references support the application of systems approaches, especially systems thinking and dynamics paradigms and methodologies, to ICZM.

2.4 The use of indicators

An indicator is a measure which provides a simplified view of a complex phenomenon (i.e. a complex system) in terms of processes and corresponding variables. The use of indicators, in fields such as economy, environment, and health is widespread and affects all levels of the decision making process (EIU, 2008; OECD, 2008; WHO, 2008).

Indicators can come as a (i) single measurement (simple indicator), (ii) a set of measurement (set of indicators), or (iii) aggregated into indices (composite indicators).

Simple indicator. Indicators can be measurements of simple phenomena providing information about a specific trend: the average temperature of the troposphere is an indicator of change in a complex system (the climate); blood pressure is an indicator of the state of a complex system (the human body).

Set of indicators. Indicators can also come in non-aggregated sets, such as the European Environment Agency core set (EEA, 2008), or the set of indicators of the Spanish Observatory for Sustainability (OSE, 2008).

Composite indicators, indicators can be based on more or less complex calculations and aggregated into indices, which measure the performance of complex systems, such as the Gross Domestic Product (GDP), the Consumer Price Index (CPI), the Human Development Index (HDI), the Environmental Sustainability Index (ESI) or the recent Happy Planet Index (HPI).

Independently from the type of indicator, they all should be designed taking into consideration few basic principles (Bossel, 1999; Jiménez et al., 2004):

1. They should be based on a deep understanding and preliminary analysis of the system.
2. They should reflect the underlying structure of the system.
3. They should be easily understandable by the targeted end-users.
4. They should be sensitive to changes in the state of the system.
5. Their measurement should be repeatable and cost-effective.

2.4.1 Common uses of indicators

The development and use of indicators is common to many disciplines and sectors.

The discipline with the highest tradition in this field is probably econometrics, which uses more or less complex statistical models to monitor the evolution of a given economic model, reflecting the economical situation of a Country, a Region, or a local community (i.e. a territorial system or administrative unit).

As an example, The Gross Domestic Product (GDP) is a measure of the national income and outputs of a country, and is commonly used to determine the economic wealth:

GDP = consumption + gross investment + government spending + (exports – imports)

Health sciences and psychology are also traditional fields where indicators are used as measures of the state of patients. The development of advanced statistical techniques in these fields has been promoted in order to improve understanding of the relationships between different variables and to identify the most suitable indicators when detecting and monitoring health problems.

As previously stated, three types of indicators can be used to monitor the state of a given complex system: (i) a simple indicator, (ii) a set of indicators or (iii) a composite indicator. The choice among these three types should be based on the analysis of the underlying structure of the system to be studied.

One example per each type of indicator is reported here, in order to highlight the differences between them: (i) the CO_2 emissions as a simple indicator of climate change, (ii) the EU set of Structural Indicators, as a measurement of progress toward the objectives of the Lisbon Agenda, and (iii) the Human Development Index, a composite indicator which reflects the state of human development in different countries.

<u>Simple indicator: level of CO_2 emissions</u>

The level of emissions of CO_2 is considered a simple indicator not because of the nature of the processes which it aims to describe, but because of the nature of the indicator itself, i.e. one single measurement having a high degree of relation (or correlation, in statistical terms) with climate change processes. Following the list of indicator's features reported in section 2.4, many points support the use of CO_2 as an indicator of climate change: (i) strong theoretical frameworks have been developed, reflecting the underlying structure of the system, (ii) it is considered as being sensitive to major changes of the climate (see, for example, Royer et al., 2007), it is easily understandable by the end-users and its measurability is relatively easy.

Set of indicators: EU Structural Indicators

The Structural Indicators of the EU (Eurostat, 2009) are designed to provide an instrument for an objective assessment of the progress made towards the Lisbon objectives, under the strategic goal of "becoming the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion". Structural Indicators are calculated each year and reported to the commission in a set of 14 indicators, divided into 6 groups (see table 2.4). In this case, no composite indicator is constructed to summarize the progress towards the overall strategic goal.

Group	Indicator
1. General economic background	1. GDP per capita in PPS
	2. Labour productivity
2. Employment	3. Employment rate
	4. Employment rate of older workers
3. Innovation and research	5. Youth education attainment level by gender
	6. Gross domestic expenditure in R&D
4. Economic reform	7. Comparative price levels
	8. Business investment
5. Social cohesion	9. At risk-of-poverty rate after social transfers
	10 Long-term unemployment rate
	11. Dispersion of regional employment rates
6. Environment	12. Greenhouse gas emissions
	13. Energy intensity of the economy
	14. Volume of freight transport relative to GDP

Table 2.4. The theoretical framework of the EU Structural Indicators.

Composite indicator: Human Development Index

The Human Development Index (UNDP, 2009) is a summarized measure of human development, through the combination of three dimensions of human expectations: (i) a long and healthy life, (ii) literacy and knowledge, and (iii) a decent standard of living.

These three dimensions correspond to three indices which are combined to calculate the HDI: the Life Expectancy Index (LEI), the Education Index (EI) and the GDP index (GDPI). Each of these indexes is calculated using a simple normalization technique which transforms raw data into 0-1 value. The HDI is an average of the three indexes:

$$HDI = \frac{(LEI + EI + GDP)}{3}$$

The theoretical framework of the HDI is simple (humans are developed if they live long lives, with a good education and enough money) and its calculation is easy as well. Despite this, the impact of the HDI is high, being the main measurement of the yearly UNDP's Human Development Report.

2.4.2 Indicators and the measurement of sustainability

Sustainable development is a type of development which meets the present needs without compromising the ability of future generations to meet their own needs. Concepts, methods and models for sustainable development have been developed in the last 30 years, within the framework of the sustainability sciences.

Three concepts of sustainability are relevant for this thesis:

1. Sustainability requires a systems approach.
2. Sustainability must be measured using indicators.
3. Sustainability principles are the base for Integrated Coastal Zone Management.

Many authors have dedicated efforts to develop theories linking the systems approach, the principles of sustainable development and the use of indicators as a way to measure the state and progress towards certain sustainability goals (Clayton, 1996; Costanza, 1996; Ronchi et al., 2002; Castro-Boñano, 2002; Gallopín, 2003).

Kelly (Kelly, 1998) supports the use of a systems approach to identify information (i.e. indicators) for sustainable development, arguing that other frameworks, such as the PSR, fail to capture important causal relationships and the system behaviors. Kelly follows Forrester's approach (Forrester, 1961) indicating three components of the decision making process: (i) the creation of a concept of desired state, (ii) the identification of the actual conditions and (iii) the actions needed to improve the state of the system to reach the desired state. She argues that most of the indicators address the first two components but fail with the third point because they lack understanding of causal relationships: systems thinking is supported as a framework useful to identify crucial information in the form of key variables in causal loop diagrams.

Espinosa (Espinosa et al., 2008) highlights the importance of stakeholders' participation in the identification of indicators. In its analysis, he brings Stafford Beer's cybernetics VSM (Viable System Model), introduced in section 2.3.1, to the field of sustainability, with a strong theoretical and philosophical background. Even if the theoretical basis of such an approach don't provide a practical approach for its implementation, this author argues that, while approaching sustainability, "the challenge is to be able to identify the essential variables which can be used to monitor the most vital aspects of the interaction between the organization and its niche: designing interventions for sustainability should shift from top down approaches to participatory bottom up approaches".

A more operational approach is found in Bossel's report to the Balaton Group (Bossel, 1999), an international network founded by Donella Meadows, author of "The Limits to Growth" of 1972. Bossel recognizes sustainable development as an objective of socio-environmental systems, which have to be translated into the practical dimensions of the real world to make it operational. Proper indicators are needed in order to recognize the presence or absence of sustainability, to tell us where we stand with respect to the goal of sustainability. He argues that the selection of the proper indicators is not a trivial process: a systematic approach is needed for the recognition of the relevant information, through the identification of models for systems functions. Some interesting concepts are also reported: (i) the number of indicators must be as small as possible, not smaller than necessary; (ii) the indicator set must be comprehensive and compact, covering all relevant aspects; (iii) the process of finding an indicators set must be participatory to ensure that the set encompasses the visions and values of the community or region for which it is developed. On the other hand, he is critique with the construction of composite indicators, as the process of aggregation may hide serious deficits in some sectors and become even more questionable when they require "adding apples and oranges". More criticisms on aggregation come from Böhringer (Böhringer, 2007) who focuses on the influence of the expert decision on the final result, in the calculation of composite indicators.

In any case, many examples of the calculation of composite indicators exist in the sustainability sciences. One significant example of the use of composite indicators to measure and benchmark sustainability is given by the Environmental Sustainability Index (ESI) developed by Yale University in collaboration with the Joint Research Centre of the EC (Esty et al., 2005). The objective of the ESI is to measure the performance of States, in "protecting and maintain their environment". The ESI is based on a set of 76 measurements (datasets) grouped into 21 indicators and 5 components. In this example, the components of the system, which describe environmental quality in each country and the capacity to maintain or enhance conditions in the years ahead, are the following: (i) environmental systems, (ii) reducing environmental stress, (iii) reducing environmental vulnerability, (iv) social and institutional capacity, (v) global stewardship. Each of these components encompasses a small group of indicators which, in turn, is calculated using data out of the 76 measurements.

The methodology used in this case follows the approach developed by JRC (Nardo et al., 2005), and is based on the following steps:

1. Step 1. Developing a theoretical framework.
2. Step 2. Selecting variables.
3. Step 3. Multivariate analysis.
4. Step 4. Imputation of missing data.
5. Step 5. Normalization of data.
6. Step 6. Weighting and aggregation.

The theoretical framework, developed by the expert group, is "built on a broad base of theory in the ecological sciences and environmental policy".

Data is collected across all countries and a multiple imputation of missing data is performed, in order to fill gaps in the datasets. After testing statistical methods, including principal component analysis (PCA) and ranking based on questions to leading experts, a final uniform weighting and simple aggregation is considered as more transparent and easier to understand.

2.4.3 Indicators for ICZM

ICZM is a continuous process for the management of the coast using an integrated approach, regarding all aspects of the coastal zone, including geographical and political boundaries, in an attempt to achieve sustainable development. Formally introduced during the UNCED conference on environment and development of 1992 (section 2.3.3) it is strictly related with sustainable development concepts and practice as it represents the implementation of its principles to the coastal zone.

The use of indicators to monitor state and progress of ICZM implementation has been explicitly suggested by the text of the chapter 17 of the Agenda 21, and extensive literature has been produced on the subject since then, based on the research carried out by the coastal science community (Bowen et al. 2003; Ehler, 2003; Hanson, 2003; Henocque, 2003; Olsen, 2003; Rice, 2003; Jiménez et al. 2004; Pickaver et al., 2004; Sardá et al., 2005; Potts, 2006; Conway, 2007; Fontalvo-Herazo et al., 2007; Rey-Valette et al., 2007; Hoffmann, 2007) and initiatives of the responsible organizations (Scottish Executive Research Unit, 2001; IOC, 2003; IOC, 2006; Martí et al., 2006; NOAA, 2007).

Moreover, the use of indicators is encouraged by the ICZM Protocol for the Mediterranean (UNEP, 2008).

The literature on coastal indicators is as extended and heterogeneous as their broad meaning and possible interpretations. In any case common principles, methodologies and issues can be distinguished. The review of these previous works has the objective to understand which principles or models are used to represent the system and how the most significant indicators are extracted.

The analyzed works can be inserted in one or more of the three following groups: (i) measurement of the sustainable development of the coastal zone, (ii) development of a problem-oriented framework to identify and select indicators at the local level (iii) measurement of a specific ICZM programme performance. The first case can be associated more strictly with sustainability models, while the second and third can be associated with a management-oriented approach at different scales.

<u>Measurement of sustainable development in the coastal zone</u>

The measurement of sustainable development in the coastal zone is commonly considered as one of the way to pursue the objectives of ICZM. In the revised works, the models of sustainable development are developed using either a generic systems approach, through the expert-based identification of the components of the system, or other frameworks such as the "orientors of viability" (Bossel, 1999), the HGF framework (Kopfmüller et al., 2001) or the PSR and DPSIR frameworks.

The DEDUCE Project (Martí et al., 2006), whose database is used to test multivariate analysis in section 5.7, aimed to implement a set of indicators for coastal sustainable development in various European regions. This experience is strictly related with the Recommendation 413/2002/EC on ICZM and the work of the Working Group on Indicators and Data (WG-ID). The WG-ID proposed a core set of 27 indicators and 46 measurements designed to monitor sustainable development of the coastal zone. This system of indicators is based on 7 goals, covering the components of the coastal system which has been considered important by the WG-ID, i.e.:

1. To control further development of the undeveloped coast.
2. To protect, enhance and celebrate natural and cultural diversity.
3. To promote and support a dynamic and sustainable coastal economy.
4. To ensure that beaches are clean and that coastal waters are unpolluted.
5. To reduce social exclusion and promote social cohesion in coastal areas.
6. To use natural resources wisely.
7. To recognize the threat to coastal zones posed by climate change and to ensure appropriate and ecologically responsible coastal protection.

This list of goals represents the theoretical framework (the model of the system) used to identify and select the indicators which are supposed to finally measure the level of sustainable development of the coastal zone.

The DEDUCE partners recognized the need to develop an integrated analysis of the calculation of the results, in order to describe the types of relationships and to uncover causes and effects relations. The key elements of this analysis are the following:

1. Defining cause-effect relationships.
2. Establish agreed thresholds and targets.

3. Weighting the relative value of the indicators.

This thesis contributes in addressing points one and three.

PSR and DPSIR frameworks deserve a closer look, considering their level of diffusion. The OECD's PSR framework and the EEA's DPSIR framework are commonly seen as appropriate to identify sets of indicators (Jiménez et al. 2004; Conway, 2007; Sardá et al., 2005; Bowen et al., 2003). The advantage of the use of PSR/DPSIR frameworks is that they are designed to qualitatively capture causal relationships between the components of the system. As an example, Conway (Conway, 2007) assessed the state of sustainable development in the Solent using the DPSIR approach to identify the system's components, and confirmed the pool of indicators using the contribution of local stakeholders.

Bowen (Bowen et al., 2003) considers the PSR/DPSIR frameworks as the best descriptor of the linkages between socio-economic conditions and changes in coastal environment. In its work, the DPSIR framework is used to identify indicators within a theoretical framework made of eight themes: (i) population dynamics, (ii) economics conditions, (iii) social conditions, (iv) building pressure, (v) habitat change, (vi) contaminant introduction, (vii) resources extraction, (viii) human uses. Despite of the interesting results, this approach can loose some significant components of the system: in Bowen's words, "when developing an indicator system, in any given situation it may be that the range of influence is wider than those characterized in these thematic categories: a systemic review of the possible causal relationships should be an early part of the design of any indicator-based effort".

This criticism is reaffirmed by Kelly (Kelly, 1998), who argues that "frameworks such as the DPSIR/PSR fail to capture important causal relationships and system behavior" and supports the use of systems thinking and dynamics approach as "it facilitates the identification of important information about the structure and behavior of systems required for the development of effective policies and actions". Also Jiménez (Jiménez et al. 2004) argues that "conceptual models" are the most realistic framework to identify the relations between indicators: the coastal function of interest should be modeled in a simple way by connecting the different indicators.

Systems thinking can then be a better alternative for system's modeling and the identification of key issues and the corresponding variables, to be used as indicators.

Development of problem-oriented approaches to identify and select indicators

Problem-oriented approaches to identify and select indicators are normally used at the local level and with the help of experts and stakeholders. An interesting approach in this sense can be found in Hoffmann (Hoffmann, 2007) who integrates coastal problems identified by stakeholders in the Oder Estuary, in Germany, into the HGF framework (coupled top-down and bottom-up approach), in order to cover all the aspects considered relevant to sustainable development.

Another approach is applied by Fontalvo-Herazo (Fontalvo-Herazo et al., 2007) who uses a participatory approach for the identification of indicators sets in the Bragança coastal villages, in Brazil. In this case public participation is used to identify stakeholders' priorities, as a base to focus on criteria and the corresponding indicators. A filtering phase is then needed to select the most important indicators. Following this approach, the filtering process aims to minimize the number of indicators and to make the system manageable. The objective is to determine the smallest number of possible indicators covering all relevant aspects and interactions in the coastal system. The author suggests the use of system's approach of Bossel (Bossel, 1999), or a final stakeholders' prioritization as possible ways for further reduction. Multivariate statistics is not considered as a possible strategy to confirm the results.

Measurement of a specific ICZM programme performance

Indicators are also used to measure performance of policies, strategies and programmes in ICZM. In this case, a "theoretical framework" to measure performance is commonly designed to link general visions with specific goals, indicators and measurements.

A comprehensive work on the subject has been done by UNESCO/IOC (UNESCO/IOC, 2003; UNESCO/IOC, 2006) through the publication of two specific manuals. UNESCO/IOC identifies different approaches to identify components and indicators: the Logical Framework, the PSR/DPSIR framework, the ICOM Cycle and Outcome-based approaches are reported as examples. In the IOC/UNESCO approach, indicators should be selected for each of the objective of the programme and the set of indicators should be prioritized based on its relevance to goals and objectives, data readiness, feasibility and other criteria. Identify the correlations among the indicators is considered important in order to understand if the indicators system as a whole makes sense.

On the other hand, Olsen (Olsen, 2003) proposed two approaches to measure programme performance: the Four Order Outcomes framework and the ICZM policy cycle framework. The four order of outcomes framework is used to identify indicators for each of the following stages (outcomes) of the ICZM process: (i) Enabling conditions (ii) Changing in behavior (iii) the harvest and (iv) sustainable coastal management. On the other hand, the ICZM policy cycle framework uses four stages of the cycles as a base to identify indicators: (i) issue identification and assessment (i.e. coastal diagnosis), (ii) programme preparation, (iii) formal adoption and funding, (iv) implementation and evaluation (see figure 2.8).

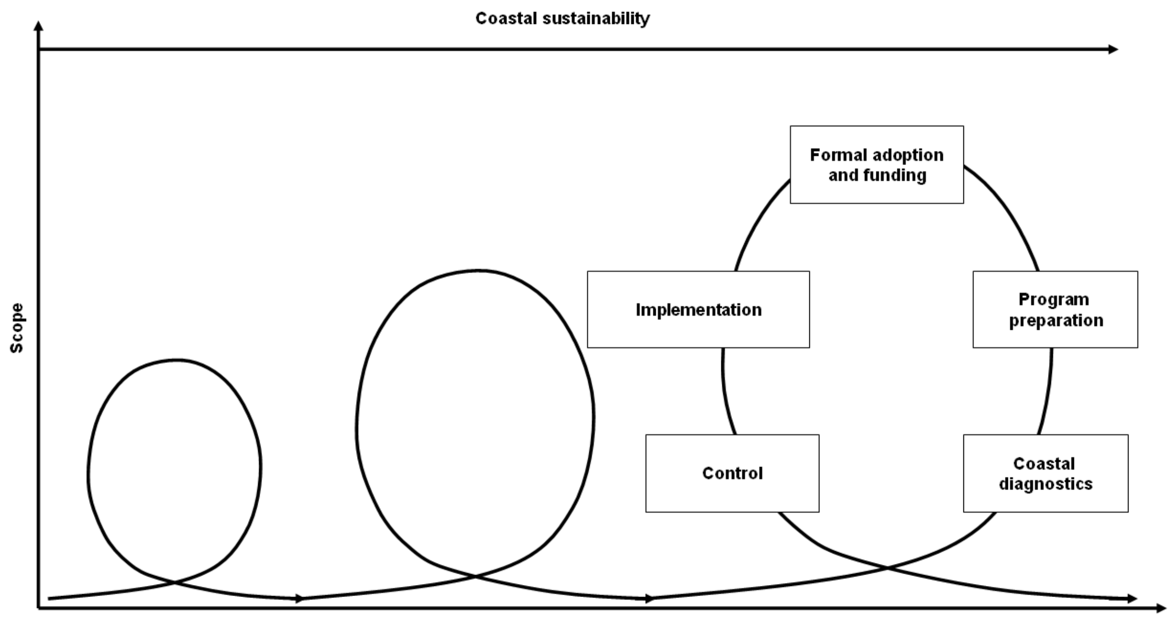


Figure 2.8. The coastal policy cycle (adapted from Olsen, 2003).

An interesting methodology is used by NOAA's Ocean and Coastal Resources Management Office (OCRM), in charge of the design and implementation of the Coastal Zone Management Act Performance Measurement System (CZMAPMS) (NOAA, 2007). This system, introduced in section 2.2.3, tracks indicators of effectiveness of the Coastal Zone Management (CZM) and National Estuarine Research Reserve System (NERRS) programs at the national level. The system consists of two components: (i) a suite of performance measures, to assess how well programs are achieving the goals of the Coastal Zone Management Act (CZMA) and their program strategic objectives, and (ii) a set of contextual indicators to provide information on environmental and socioeconomic factors influencing program actions. A panel of experts worked to develop the framework for identifying performance indicators. The contextual indicators are reported as follows. (table 2.5).

US national Coastal Management Program
Suggested Contextual indicators
Population in the coastal zone
Employment in the coastal zone
Infrastructure investment in the coastal zone
Water quality
Endangered species identified in the coastal zone
Area subject to coastal hazards
Coastal land cover change
Habitat of particular concern, as identified by each state
Type and quantity of commercial and recreational shellfish areas
Coastal dependent employment
Coastal dependent business

Table 2.5. Contextual indicators of the CZMA Performance Measurement System (NOAA, 2007).

ICZM progress and performance can be also evaluated using specific questionnaires designed to involve actors involved in coastal policy implementation. ICZM progress was a hot topic during the implementation of the Recommendation 413/2002/EC on ICZM and a working group on indicators and data (WG ID) was then created. In this context, Pickaver (Pickaver et al., 2004) proposed 26 questions divided into five phases of ICZM, in order to see where coastal management responsible organizations stand in terms of implementation.

Using a similar approach Henocque (Henocque, 2003) designed a set of indicators based on the responses to specific questions, in order to assess local experiences in costal management in France.

<u>The use of multivariate statistics for coastal indicators</u>

The use of multivariate statistics for coastal indicators is not as common as in other fields of knowledge such as econometrics and health sciences.

Multivariate statistics is considered by only few authors as a way to explore complex coastal systems (Jiménez et al., 2004; Rice, 2003).

An interesting experience in this sense is made by Sardá (Sardá et al., 2005), who uses the DPISR framework to identify a set of indicators, in order to measure the level of sustainable development at the local level and principal components analysis (PCA) to reduce the number variables into a strategic set of indicators.

Another, interesting approach is used by Shi (Shi et al., 2004), who envisages the sustainable development of the coastal zone as a complex system with an ordered structure, which can adjust itself to external influences. This complex system is divided into three sub-systems: (1) environment and resources, (2) economic development and (3) society. This theoretical framework, which is based on the expert knowledge, is used to select the final set of indicators. In order to summarize the information into synthetic indices, a multivariate analysis is carried out, where PCA is used to eliminate overlapping information in basic indicators and to assign weighs used to calculate the value of the proposed indices of coastal sustainability.

Without doubts, the use of appropriate statistical techniques can improve the final set of indicators, through the selection of the most important components in terms of variability and through the exploration of causal relationships between variables.

2.5 Discussion and conclusions

This chapter introduced ICZM principles, with some relevant experience in Europe and the Mediterranean, the systems approach to management and the use of indicators in different disciplines. The objective the chapter was to identify the knowledge gaps in the state of the art and to drive the research towards more systematic ways to identify problem-oriented indicators, to be used to implement ICZM initiatives in different geographical contexts.

ICZM is a broad concept which includes many different and complementary aspects, with a clear objective of promoting more environmentally sound, economically efficient and democratic ways of managing the coastal zone, a complex socio-environmental system.

The systems approach is a broad field of knowledge which provides methodologies to model complex systems and to improve its understanding. The most common applications include operations research for large industries, strategic management of companies and environmental resources, such as water. Experiences in the use of the systems approach in ICZM exist, even if most of them are not brought into practice.

The performance and behavior of these complex systems can be analyzed and monitored using indicators, in form of simple indicators, sets of indicators or composite indicators.

Indicators are developed and used in different fields, having a strong impact in high-level decision-making: this is the case of composite indicators such as the GDP, a common measure of the economic wealth of human systems.

Indicators can also be used to measure sustainability in the coastal zone and/or the performance towards the goals of a given ICZM programme. Different approaches are currently proposed to identify sets of indicators for ICZM, being the systems approach recognized by some authors as one of the most appropriate. Despite of this, little experience exist in drafting and testing system's models to identify critical information for coastal management, while the identification of problem oriented indicators is fundamental to drive the system towards sustainability.

In conclusion, integrated management of the coastal zone needs to be based on a systems approach, which takes into consideration the multiple aspects, components and relations which can affect decisions regarding large scale plans or local coastal projects. Decisions should be based on a deep understanding of the system's functioning and rely on the right information: a clear picture of the system, including its components and relations, should be the base to identify a reduced number of key indicators to be used to drive the system, according to a set of management objectives.

CHAPTER 3 – EXPLORATION OF COASTAL SYSTEMS: INTEGRATING KNOWLEDGE WITH PERCEPTION

3.1 Introduction

ICZM deals most of the time with complex, unstructured problems, where many technical aspects and multiple interests are brought together. A structured analysis is therefore needed in order to frame complexity through comprehensive problem scoping and problem formulation and system diagnosis, based on the contribution of sector experts and interested stakeholders, integrating knowledge with perception.

In this chapter, four case studies are reported as examples of complex, unstructured problems in the coastal zone, from beach management at the local level to ICZM strategies at the national scale. Each case study is based on the experience gained in real ICZM projects where different techniques have been tested to involve coastal stakeholders and to identify critical issues which should be tackled to improve coastal sustainability.

This chapter is divided as follows:

- Section 3.2 deals with the complexity of coastal problems and gives the theoretical basis for problem classification and exploration in socio-environmental systems, introducing policy analysis as a broad methodological framework.

- Section 3.3 provides ideas and observations on the role of coastal experts and coastal stakeholders and reports some relevant techniques for stakeholders' identification and involvement.
- Sections 3.4, 3.5, 3.6 and 3.7 report different examples of complex problems in coastal systems, in four different cases: (i) when stakeholders must be identified for the development of a strategy for the coastal zone at the national level (ii) when different alternative solutions are available to solve a beach management problem, (iii) while preparing a broad coastal profile for ICZM planning and (iv) when a group of experts is in charge of identifying a set of coastal indicators.

The critical revision of these experiences, supported by examples and theories from the literature, is the base to answer the first research question (see section 1.2):

How can we explore a coastal system in order to improve knowledge and understanding of the issues at stake?

3.2 Dealing with complex problems

As Ackoff says (Ackoff, 1974), successful problem-solving requires finding the right solution to the right problem: failure is caused most of the times by the solution of the wrong problem than by the solution itself.

Problem-formulation involves focusing on the right problem. The importance of problem-formulation is clear, as many efforts in a project will be directed to a quest for the right solution or for the right set of alternative solutions.

When the problems are complex, problem-formulation is not an easy task, and the understanding of the system is the base for further steps.

To deal with complex problems we first need to understand complexity. Complexity is strictly connected with the concept of system (see chapter 2) and with understanding of complex systems. Complex systems are made of many, interconnected components: the relations between these components give rise to emergent properties of the whole which are far from being understood using classical deterministic approaches.

When dealing with problem-solving in coastal systems, complexity arises when non-deterministic components, whose behavior is seldom predictable or unpredictable, are to be included in the system model. The integrated set of components, including physical, ecological, social and economic sub-systems, can hide relations which are not considered if we deal with only one of the sub-systems, which can have a set of deterministic models already available for use (e.g. the physical sub-system, the economic sub-system).

Coastal projects in complex socio-environmental systems need to be tackled taking into consideration the system as a whole, including physical, ecological, social, economic and administrative sub-systems: problem-solving based on the analysis of only one component of the coastal system often brings unintended consequences to the real system's behavior.

Integrated coastal zone management deals most often with the relations between components belonging to different sub-systems, by definition a complex problem. Most of the problems in coastal management are then as complex as their components are interconnected, there is no clear solution, different actors view problems differently and their views change over time.

3.2.1 The problem-solving process

Figure 3.1 (Bots, 2002) is a good example of a diagram of the problem-solving process. In this case, the problem owner wants to solve a problem in a given system, a set of different instruments is available, with no clear understanding of the effect and the possible unintended consequence of the strategy chosen. Furthermore, other stakeholders have a different vision of the same system and their objective can differ from the ones of the problem owner.

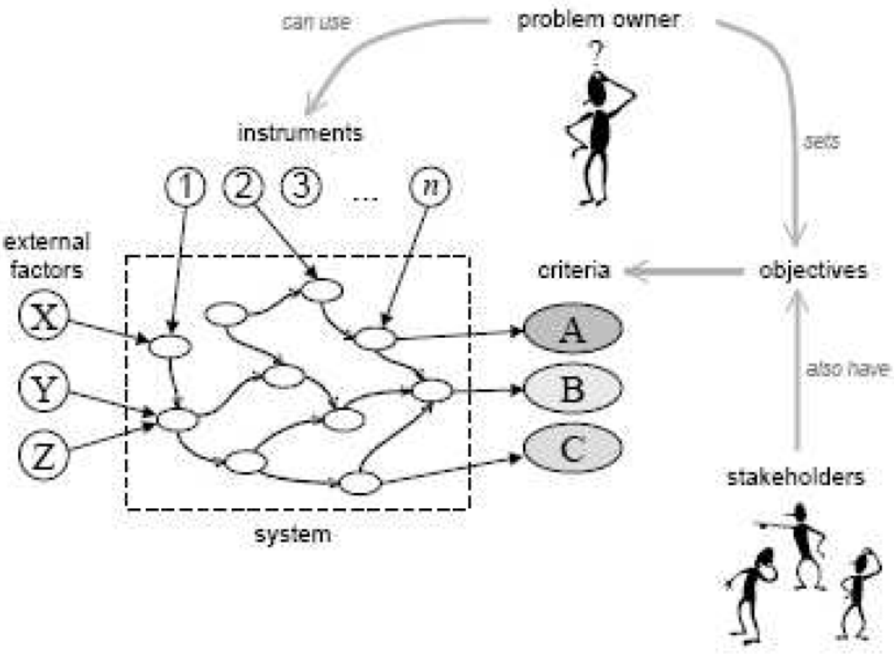


Figure 3.1. The problem-solving process in multi-actor systems (from Bots, 2002).

Integrated problems in complex socio-environmental contexts cannot be solved by means of reductionism only. The understanding of the problem could also require qualitative (systems thinking) semi-quantitative (systems dynamics) and quantitative (multivariate analysis) techniques which should be used when the system is too complex to be modeled using traditional techniques. The following table (table 3.1) represents a scheme of increasing complexity, from the physical sub-system to the socio-economic sub-system, and the possible approaches and techniques which can be used. In the table, only some typical coastal problems are reported as examples.

Complexity	Sub-system	Issue	Tools
	Physical	Coastal erosion, port construction, water discharge	Experimental design, numerical models
	Ecological	Dunes degradation, sea grass destruction, invasive species	Field surveys, lab analysis
	Socio-economic	Tourist development, Land use, conflicts between uses	Participatory approach, systems approach

Table 3.1. As complexity increases, different issues, approaches and tools should be applied.

3.2.2 Structured and unstructured problems

Most management processes in complex socio-environmental systems have few clear problems with one problem owner, a single definition of the problem, a small number of actors and one solution: called a structured problem (Thissen, 2008). Most problems are instead characterized by multiple stakeholders, different points of view and interests and a set of alternative technical solutions: this is called an unstructured problem.

A classification of problem typology is proposed by Enserink (Enserink, 2005), based on the balance between knowledge (in technical terms) and values (in the stakeholder view) and a classification of problems into structured, poorly structured, ill-structured and unstructured (table 3.2).

		Consensus on values?	
		NO	**YES**
Consensus on knowledge?	**NO**	Unstructured problem	Moderately structured problem
	YES	Ill-structured problem	Structured problem

Table 3.2. Classification of problems based on the balance between values and knowledge (from Enserink, 2005).

Most of the problems we are dealing with in coastal zone management are unstructured: an integrated, systems approach is needed formulate the right problem, create a clear picture of the system and improve the understanding of its processes and patterns of behavior.

3.2.3 Framing complexity with policy analysis

The process of unstructured coastal problem-solving, from the local scale of coastal interventions to that of national ICZM strategies, is intrinsically multidisciplinary, the coastal system being a complex environment where physical dynamics, ecosystem functions and socio-economic processes are strictly connected in a relatively small space.

A multidisciplinary and systems approach is therefore needed to solve coastal problems: the field of policy analysis provides a broad framework to identify optimal solutions and to develop methodologies such as system profiling, public participation, systems thinking or statistical modeling.

Policy analysis is a method whose purpose is to assist the problem owner in choosing a preferred course of action from among complex alternatives under certain conditions, for a given set of objectives and which can be executed for the preparation of strategies, plans and projects. The use of policy analysis methodologies has clear advantages when social issues are involved and there are many contradictory interests, non-comparable values are to be judged and many values must be compared: this is the situation of complex, unstructured problems (Verhagen, 1998).

Research centers and consulting firms have recently paid great attention and have attached importance to policy analysis as an independent field of work. As examples, Deltares, a Dutch knowledge hub in the field of water and environment and DHI Water & Environment, a well known Danish consulting firm, are both dedicating specialized departments, staff and research activities to policy analysis, covering areas such as diagnostic assessments and institutional analyses, policy formulation, legislation and overall sector reforms, facilitation of stakeholder involvement, human resource development and capacity building. In a world of increasing complexity, strategic advice on complex systems is therefore gaining importance, and traditional environmental assessment techniques are being replaced with more integrated approaches where the consequences of strategies are not considered as side-effects which should be minimized but as parts of the results of overall policy implementation.

In sum, policy analysis is a framework for many different tools and approaches to complex problem-solving. These tools and approaches include the ones reviewed and tested in this thesis:

- Stakeholders identification techniques.
- Integrated coastal profiling and diagnostics.
- Identification of key issues and variables.
- Modeling the system using systems approaches.
- Analysis of the system using multivariate statistics.
- Identification, selection and delivery of indicators for coastal management.

3.2.4 Framing policy analysis interventions

An interesting approach to framing policy analysis has been developed by Mayer (Mayer et al., 2004), who describes policy analysis as a field which gathers different methods and activities, from qualitative to quantitative. In order to give a structure to policy analysis activities, Mayer proposes a framework for positioning the different perspectives and to focus on the implications in project policy analysis. A cluster of six activities is identified with which the policy analyst should normally work:

1. Research and analyze. Focus on gathering data and information. In coastal management this includes definition of the problem (as previously discussed) collecting data and information (including actors' analysis) and preliminary diagnosis (also called coastal profiling).

2. Design and recommend. Provision of alternative solutions to the problem owner. In coastal management this includes the design and testing (modeling) of alternative solutions, and analysis of their effect on the overall system.

3. Clarify arguments and values. Improve the understanding of policy issues to improve the quality of debate among stakeholders.

4. Provide strategic advice. Provide the client (the problem owner) with the right arguments to support a solution not clearly seen by public opinion as the best.

5. Democratize. Give the same opportunities and improve public access to information in coastal management.

6. Mediate. Conflicts between different interests often arise around public initiatives. Application of conflict-resolution techniques.

In sum, policy analysis is a framework to analyze complex socio-environmental systems and the effects of alternative solutions. Policy analysis includes the methods proposed in this thesis, designed to create a picture of the system based on the integrated exploration of all aspects which may affect system behavior, ultimately aiming to identify critical indicators which should be monitored and used for coastal system management.

3.3 The role of coastal experts and stakeholders

When dealing with complex, unstructured problems in coastal zones, experts play a major role in the identification and characterization of the system components.

Coastal experts (ecologists, geologists, engineers, economists, lawyers, geographers, sociologists, lawyers) normally contribute to the knowledge and understanding of one sub-system's variables (physical, ecological, socio-economic and administrative), but the interactions between these variables are often not easy to unravel: group interaction should therefore address the design of a system model, where relations between variables are as important as the variables themselves.

The term stakeholders on the other hand refers to a group of people who must be taken into consideration by managers and leaders when proposing a new initiative that could affect their interests.

In policy analysis, the terms stakeholder, actor and agent can be considered as synonyms even if they have slightly different meanings depending on sectors (business, policy, etc.) and regions (Europe, US, etc.). In business terms, stakeholders are any group or individual which may affect or be affected by the achievement of an organization's objectives (Freeman, 1984). In ICZM, stakeholders are normally groups, represented by individuals, who affect or can be affected by the execution of a single project, implementation of a plan or the design of a broad strategy for the coastal zone.

Coastal initiatives may fail in large part because decision makers fail to deal with the interests of key stakeholders.

Failure of coastal initiatives includes non-implementation, partial implementation or poor results (Nutt, 2002). Failure is therefore associated with the lack of recognition of complex problems with multiple facets, each of particular concern to a specific group of people: the involvement of these people and the exploration of their problems and objectives can be a decisive factor for a successful project, and must be considered an integral part of the process.

There are many different analysis techniques for stakeholder identification and involvement. Bryson (Bryson, 2004) identifies four categories: (i) organizing participation, (ii) creating ideas for strategic interventions, (iii) building a winning coalition around the development, review and adoption of proposals and (iv) implementing, monitoring and evaluating strategic interventions. All these techniques are simple in concept and should rely on facilitating material which can be used during specifically designed workshops, making it possible to incorporate key stakeholders' contributions.

In Bryson's words, a "participatory approach represents an expenditure of resources that typically is minuscule when compared with the costs of a poor performance, or even disaster, that typically follows in the wake of failing to attend to key stakeholders, their interests and their information".

3.3.1 Identification and selection of coastal stakeholders

The identification of key stakeholders must be carried out during the first stages of integrated coastal projects and should not be considered as "something that the environmental legislation asks for" or "part of modern good governance principles" but as a part of and the problem itself.

In complex socio-environmental systems, where multiple interests apply, bringing together the right people (the key stakeholders) is a way of building consensus, to avoid early-stage conflicts, to push the process forward against delays and to promote initiatives which share decision-making responsibility.

The process of identification of the stakeholders who have a real interest, who can influence and/or bring in useful proposals, is not an easy task, and should be done by integrated management specialists. Specialists can identify the most appropriate technique depending on the context with the help of the problem owner or local people who have in mind a good picture of the situation (see for example section 3.5).

A technique for stakeholders' identification is the so-called hydra model, where key stakeholders are identified in an iterative process starting from the problem owner and finishing when stakeholders identify each other, usually after three rounds (see section 3.4).

In any case, not all stakeholders with any type of interest should be involved in the process, but only the key stakeholders, to optimize participatory activities and push the project forward.

Key stakeholders should be representatives of key organizations (public administration, corporate associations, NGOs, neighborhood assemblies, etc.), even though, at the local scale, private citizens interests may also be taken into consideration. In any case, opening an active participation process up to any private citizen can sometimes generate a great muddle, no help in reaching a consensus.

Following Areizaga (Areizaga et al., 2005), a specific role should be assigned to the actors by subdividing them into (i) dependent (who live and/or work on the coast, e.g. fishermen, the maritime sector) (ii) influent (whose interests lie on the coast, e.g. environmentalists, surfers, beach users) (iii) those who have responsibilities for its management.

3.3.2 Involvement of coastal experts and stakeholders

Once stakeholders have been identified and classified based on their influence, their opinion should be incorporated in a way which is useful to the aims of the project. At the same time, coastal experts should be brought in, to provide a deeper insight into the coastal processes involved.

Everybody should be able to participate in an ICZM process, at different levels of participation and with different mechanisms, depending on: (i) the scale of the process (regional plans vs. local initiatives), (ii) responsibility (elected representatives vs. lobbies) and (iii) the number of stakeholders involved (figure 3.2).

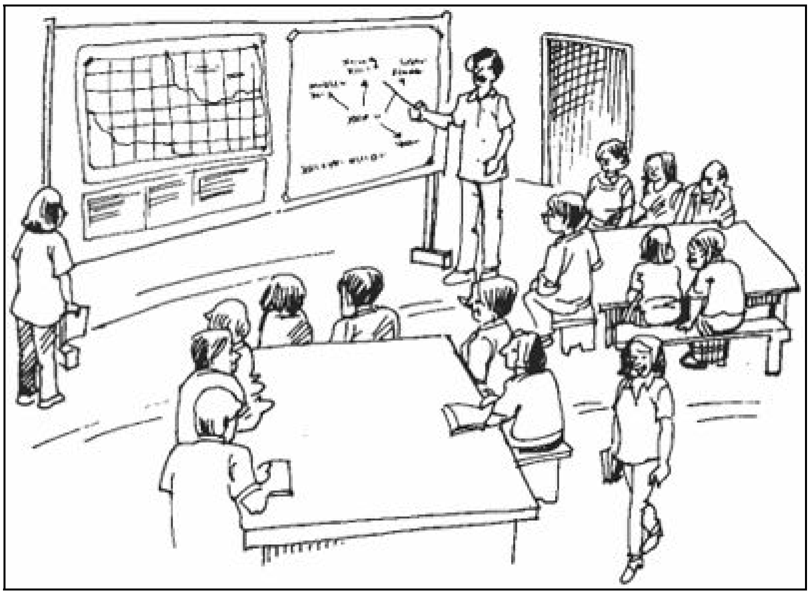


Figure 3.2. The participatory workshop, a good ICZM practice.

Various models are available to involve stakeholders in a new public initiative (see for example García, 2008). The following are the most common instruments and practices for starting a public participation and consultation process:

<u>Survey</u>: The stakeholders identified can be consulted using a questionnaire about issues addressed by a specific project.

<u>Public presentations</u>: conferences open to all the public should be promoted to report on the main issues and the ideas, proposals and alternatives for solving them.

<u>Participatory workshop</u>: round tables to reach a consensus should be composed of experts and selected people directly involved in the ICZM process from different sectors of the administration and local communities. Different techniques are available for these purposes, from participatory factsheets (section 3.5) to group model building (chapter 4).

<u>Technologies</u>: besides the infinite number of possibilities offered for capturing people's opinions on the Internet, participatory spatial planning is one of the forms of public participation which is growing in importance and impact, with advances in IT. PPGIS can be implemented with user-friendly procedures backed by commonly-used platforms such as Google Earth, or directly scratched on paper maps and then added to a GIS database.

3.4 Case study: Stakeholder identification for the Spanish Coastal Sustainability Strategy.

The Spanish Coastal Sustainability Strategy, an initiative to promote ICZM at the country's national level, was introduced in section 2.2.6. This broad initiative includes a large number of activities and products, with stakeholder identification, classification and involvement a part of the whole process (Sanò et al., 2009).

Following Recommendation 413/2002/EC on ICZM, an inventory of actors, laws and institutions was first completed (Ministry of the Environment , 2006) and IH Cantabria was responsible for different tasks.

It was considered appropriate in Spain's case for the stocktaking to include the list of all stakeholders, including public institutions at the state, regional and local levels, research institutions, business sectors, and NGOs.

Stakeholders were identified in an iterative process using the so-called hydra model (one head generates more heads): local offices of the Directorate-General of Coasts in the Ministry of the Environment prepared a short list of actors in each province who were asked to complete the list with any missing players. Finally these missing players were asked to complete the list with others still not included. The iterative process finished when no more actors appeared on the lists, usually after three rounds (figure 3.3).

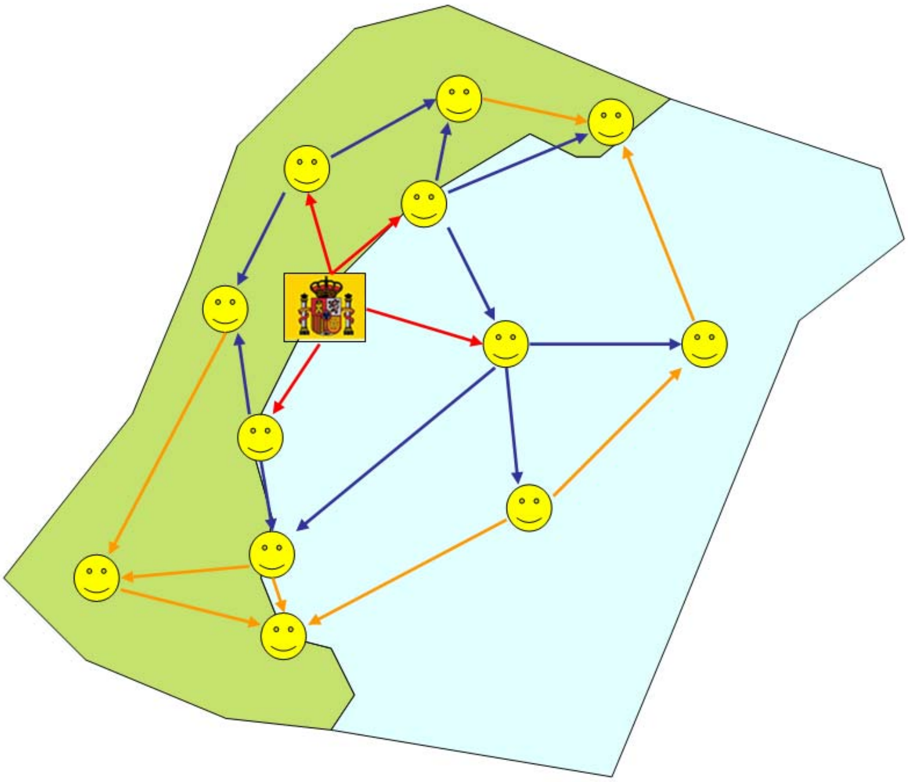


Figure 3.3. The stakeholder identification process: the organization responsible for coastal management (in this case the local office of the Directorate-General of Coasts in the Ministry of the Environment) identifies the first four stakeholders (red arrows). These stakeholders are asked to identify other possible stakeholders (blue arrows) and so on (orange arrows) resulting in a complete list of those interested. This method is called the hydra model (from Sanò et al., 2007).

The stakeholders identified were then involved in two activities:

- All stakeholders were required to fill in a survey on the state of the coast and on progress in ICZM.
- Responsible stakeholders in key sectors in each coastal region were invited to be involved in participatory workshops for the integration of plans.

The aim here was to identify all stakeholders who should have a role in coastal planning and management at the regional level. The system approach is used in this case as a way of building a system model based on existing sectors of interest (i.e. environment, infrastructures, agriculture, fisheries, etc.). The results of the experience (Sanò et al., 2007) are represented by a database of 500 Spanish national stakeholders, including their opinion regarding the state of the coast, the importance of the different sectors and the state of coastal management. This invaluable information can be used as a base to design a model for the coastal system and to address the identification of critical indicators.

3.5 Case study: beach management in Finale Ligure, part I.

The quest for the right solution in coastal erosion management can be a good example of a problem which appears simple at first sight but which turns out to be a complex, unstructured problem.

A practical experience is represented by the erosion problem on the beaches of Finale Ligure, a small coastal town in the North of Italy (figure 3.4).

Figure 3.4. Finale Ligure coastal zone, Italy.

In this case, beach tourism is the local economy's main resource, and sand erosion is considered a major problem. In June 2007, the Municipality of Finale Ligure (the problem owner), responsible for major coastal works, contacted IH Cantabria (the consultant) to find long-term solutions to its problem.

Dealing with this problem using a system approach requires, as a first step, the identification and analysis of the multi-actor system and their problems and objectives.

In this case the actors, following Areizaga (Areizaga et al., 2005), identified by the problem owner, were classified by subdividing them into (i) stakeholders whose interest lies in the coastal zone, including those living there (ii) stakeholders who live off its resources and (iii) those responsible for its management.

The consultant suggested holding a public meeting with the main stakeholders involved, to explore problems and objectives and to build a consensus around existing problems and possible solutions. In this way, a broader vision (a bigger picture) of the system was provided: while the municipality considered beach nourishment to be the main issue, bringing together different stakeholders added different perspectives to the beach management problem and proved a more effective way of finding alternative solutions (table 3.3).

Actor	Role	Problem	Objective
Municipality	Responsible	Coastal works	Consensus on coastal interventions
Beach resorts	Dependent	Loss of beach area	Long term beach maintenance
Environmental Agency	Responsible	Beach environ-mental health	Control of the chemical quality of sand (Implementation of the beach nourishment protocol)
Environmental Conservation NGO	Influent	Coastal habitat threats	Protection of sensitive coastal habitats
Fishermen's association	Dependent	Fishing catches	Maintenance of fish stocks
Port authority	Influent	Navigational safety	Navigability of the port entrance
Regional administration	Responsible	Broad scale coastal planning	Implementation of regional coastal plan
Tourists	Dependent	Dust in sand	No dust in sand, transparency and good status of bathing waters
Surfing association	Influent	Worsening surfing conditions	Improvement of surfing reef

Table 3.3. Roles, problems and objectives in a multi-actor coastal system

This example illustrated how an apparently simple problem should be seen in a broader context (in spatial and temporal terms), taking into consideration different perspectives (multiple actors) to be able to identify the optimal strategy and build a shared understanding of its implications over a long-term perspective.

A simplified version of the balanced scorecard (BSC) developed for strategic planning by organizations (see as an example Papalexandris et al., 2005), but also to analyze the overall effect of coastal interventions (Verhagen, 1998), was tested for the Finale Ligure project (IH Cantabria, 2008). The BSC includes four different alternatives and sixteen criteria, identified as critical for decision-makers (table 3.4).

This framework can be regarded as a picture of a system made up of 16 variables. Each alternative solution has a different effect on the whole system.

In this case, the consultant delivered the scorecard to the decision-makers in order to provide a broad vision of the system and improve understanding of the costs and benefits and possible unintended consequences of their choices.

		Alternatives			
		1. Backpass (emerged beach)	2. Backpass (submerged beach)	3. Nourishment with quarry sand	4. Port channel dredging
Beaches		Finalmarina, Finalpia	Finalmarina	Finalmarina, Varigotti	Finalmarina, Varigotti
CRITERIA	1. Origin of the sand	Upstream emerged beach	Submerged beach upstream from the port	Mining quarry	Port sand bars
	2. Volume moved	6250 m3	5250 m3	7500 m3 (Finalmarina, 5250 m3, Varigotti, 2250 m3)	13000 m3
	3. Volume added	0	0	7500 m3	13000 m3
	4. Length of beaches	Finalmarina: 1150 m Finalpia 450 m Total 1600 m	1150 m	Finalmarina: 1150 m Varigotti: 1500 m Total: 2650 m	Finalmarina: 1150 m Varigotti: 450 m Total: 1600 m
	5. Volume per meter of beach	3.9	4.5	2.8	8.1
	6. Length of nourishment	Finalmarina: 580 Finalpia: 125 Total: 705	285 m	Finalmarina: 300 m Varigotti: 495 m Total: 795 m	(No data available)
	7. Beach progradation	5 m	5 m	5 m	(No data available)
	8. Durability	High	Medium	High	Low
	9. Mean grain size	Finalmarina: 1,44 mm Finalpia: 1,35 mm	1 mm	1 mm	0,5 mm
	10. Technical quality of sand	High (natural sand)	Medium	Low (grain size, % fine)	Low
	11. Quality of sand for users	High	High	Low	High
	12. Environmental impact	Low (No interaction with biocenosis)	Medium (Dredging at sea)	Medium (Percentage of fine sediments)	Medium (Percentage of fine sediments)
	13. Risk of conflicts	High (sand movement between private concessions)	Low (sand movement is not visible)	High (sand skewness, dust)	Basso
	14. Risks of technical-administrative delays	Low	Medium	Medium	High
	15. Cost €/m3	10 €	15 €	20 €	0 € (service paid by port authority)
	16. Cost, total €	62.500 €	80.000 €	150.000 €	0 €

Table 3.4. Scorecard reporting the performance of four coastal restoration alternatives (from IH Cantabria, 2008).

In general, use of integrated techniques should be seen as a central part of any project in complex socio-environmental systems, not just a set of compulsory assessments to evaluate the side effects of alternative solutions such as environmental impact assessments or strategic impact assessments.

The importance of this approach is clearly stressed by Sterman (Sterman, 2000), a policy-analysis and systems thinking guru:

"In reality there are no side effects, only effects. The intended effects, the ones we thought that were beneficial for the system, are called intended effects. The effects we didn't anticipate, the effects which fed back to undercut our policy and to harm the system are the ones that we claim as being side effects, but they are only a sign of our poor understanding of the system as a whole".

3.6 Case study: The Matruh-Sallum ICZM Plan (MSICZMP), Part I

The Matruh Sallum ICZM Plan (MSICZMP) is an AECI Project executed by IH Cantabria in Egypt during the period 2006-2009.

In this case, the Egyptian government is trying to develop the stretch of coast between the cities of Marsa Matruh and El Sallum on the Mediterranean coast economically and demographically (figure 3.5), while at the same time maintaining sustainable use of its natural resources and protecting its cultural heritage and the local population. The institutions responsible (the problem owner) were aware that the design of an Integrated Coastal Zone Management Plan is the starting point to define and promote economic activities compatible with the system's carrying capacity.

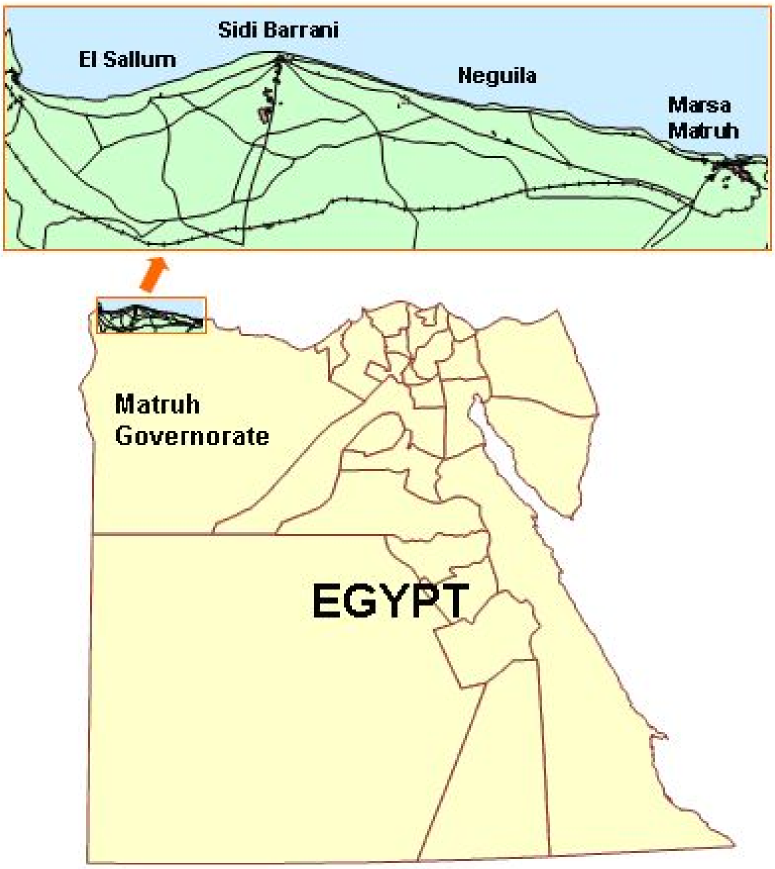


Figure 3.5. Area of study of the Matruh-Sallum ICZM Plan (from IH Cantabria, 2007).

The aim of Phase I of the MSICZMP Project was to carry out a coastal profile and diagnosis of the issues at stake (IH Cantabria, 2007). The methodology applied was based on analysis of the physical, ecological, social and the administrative sub-systems. The aim of the analysis of each of sub-system was to create a broad picture, identify the main coastal issues and be used to select the most appropriate problem-oriented set of indicators.

Chua's revision of coastal profiling (Chua, 2006) is helpful in understanding the role of coastal experts in the construction of a broad picture of the system. A coastal profile is a comprehensive description of a coastal zone covering bio-geophysical characteristics, resource-use patterns, socio-economic settings, the state of the marine and coastal environment and legal and institutional arrangements. Coastal profiling is considered the base for further planning in the coastal zone and is ideally developed by a multidisciplinary team in a variable period of time, normally 6 months to 1 year. The following are the objectives of a coastal profile:

1. To establish qualitative and quantitative baseline information.
2. To determine issues and priorities for addressing these issues.
3. To identify critical data gaps.
4. To contribute to the development of a coastal strategy.

A coastal profile was conducted in the MSICZMP project by analysis of each sub-system, carried out by a team of experts including coastal morphologists, hydrologists, biologists, and socio-economists (see table 3.5 for details).

Sub-system	Items
Physical	Regional geology
	Coastal geomorphology
	Climate
	Hydrology
	Soil characteristics
	Physical and chemical oceanography
	Marine dynamics
Ecological (Terrestrial)	Biogeography
	Ecosystems
	Flora and fauna
Ecological (Marine)	Biogeography
	Ecosystems
	Flora and fauna
Social	Demography
	Culture
	Cultural heritage
	Minorities
	Gender issues
	Coastal uses
Economic	Economic sectors
	Land-use
	Basic infrastructures
	Employment
Legal and administrative	Legal framework
	Public administrations and decision-making
	Public participation
	Sector plans and programmes

Table 3.5. Sub-systems and items analyzed for the MSICZMP Project, as a base for the coastal diagnosis.

The coastal profile of the MSICIZMP project was completed with the help of local stakeholders identified using the hydra model.

A participatory workshop, involving key stakeholders, had the following objectives:

- To include stakeholders' knowledge of the area in order to improve the analysis and diagnosis carried out by the expert team.

- To include stakeholders' opinions and views in the definitions of alternatives for sustainable development.

The meeting was attended by almost 30 people representing regional and sector administrations, the project team of experts, international organizations and the local population.

The major findings of the coastal profile were set out by the members of the project's team of experts on one hand, while representatives of other regional and sector administrations presented their sector plans for the area, where these existed. Factsheets regarding major findings for the physical, ecological and socio-economic system, together with a SWOT analysis, were provided to the participants as support material (see Sanò et. al., 2007).

An empty public participation factsheet was also provided, to collect the contributions of the workshop participants. These factsheets had some empty space where the participant could write information on the area by filling in the following boxes:

- Information, opinions, problems and opportunities for the physical system.
- Information, opinions, problems and opportunities for the ecological system.
- Information, opinions, problems and opportunities for the socio-economic and administrative system.
- Opinion on the results of the SWOT analysis.
- Special elements to be described and pointed out on the map.
- Preliminary proposals for zoning, new elements and drawings to be added to the map.

Each of the workshop participants was then asked to (i) follow the thematic presentations given by the speakers from the project team concerning each of the components of the coastal system (ii) read carefully the information given in the factsheet and (iii) fill the Public Participation factsheets (figure 3.6)

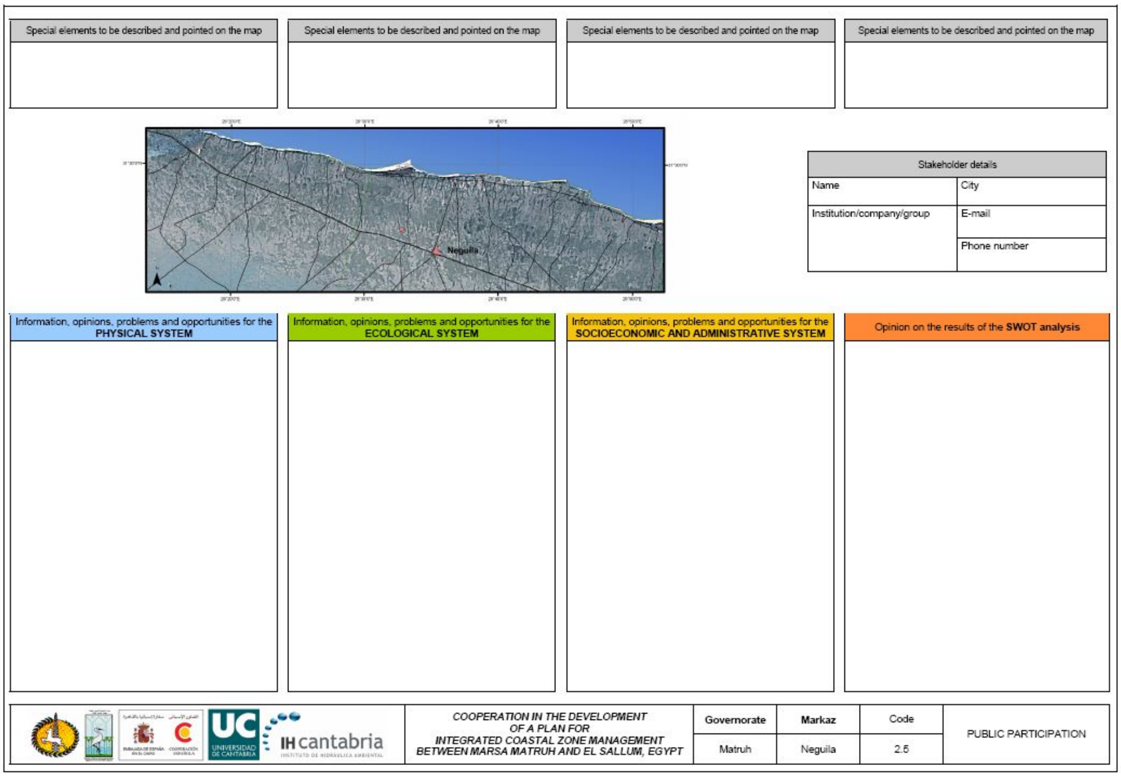


Figure 3.6. Public participation factsheet, to be filled by stakeholders during the MSICZMP workshop (from IH Cantabria, 2007).

The information organized in the coastal profile, integrated with the participatory factsheets, provided a broad vision of the coastal system as a base to detail key issues and variables for problem-oriented management.

Undoubtedly, the contribution of local stakeholders was fundamental to identify new issues by providing different points of view of the problems at stake.

An interesting experience in this sense is reported by Varghese (Varghese et al., 2008), who proposes a group interaction methodology using the systems approach to identify critical variables for coastal profiling.

Varghese's work was developed in the framework of an ICZM project in the State of Goa, India (ICMAM Project). In this case, very little information was available on the key factors affecting the areas and this information, following the author's approach, had to be elicited and prioritized based on group interactions. This was done through a systems approach in identifying coastal habitats, coastal sectors and activities, and finally entities involved in each activity. Each activity was characterized by a set of "attributes".

In this example, the experts' group interaction was guided by dedicated software which systematically created the broad picture of the coastal system. The final result is a set of variables whose importance is prioritized on a scale of 1 to 5 by the experts' group. Table 3.6 reports the identified components and variables.

Activities	Impacts	Entities	Attributes	Concern of impact
Shipping	Oil pollution	Vessel	No. of vessels	2.0
		Oil	Quantity of oil spill shipping	
		Coastal water	Sea-water oil pollution level	
	Ore pollution-induced turbidity	Barges	No. of barges	2.0
		Ore	Quantity of ore-spilled shipping	
	Turbidity of water	Coastal water	Sea-water turbidity level-sand	2.5
Dredging and dumping		Coastal water	Sea-water turbidity level-ore	
		Dredged material	Quantity of dredged material	
	Biodiversity loss	Marine species	Species population-Beach and coastal waters	3.0
Revenue and job-creation	Revenue generated	Port employees	Per-capita income port	5.0
		Port revenue	Port tax revenue	
	Jobs created	Port employees	No. of employees – Port	3.5

Table 3.6. Identification of critical variables for coastal profiling, ICMAM Project (from Varghese et al., 2008).

These examples demonstrate how, using a systems approach, group interactions can provide a broad picture of the system and identify the components of the coastal system together with the corresponding variables.

Experts definitely provide a vision of the system's functioning, but the ideas and perception of local stakeholders are fundamental to produce a broader picture as a base for system modeling.

Notwithstanding the interesting results, further effort is needed to identify interactions and causality between the system's components, in order to draft a model for the whole system made up of interconnected variables (see chapter 4).

Moreover, if data are available, the variables making up the model can be further analyzed using multivariate techniques, to understand interdependencies and ultimately identify the most suitable set of indicators (see chapter 5).

3.7 Case study: the Spanish expert group on indicators

A comprehensive review of previous experience in the use of indicators to measure sustainability and coastal management performance was carried in chapter 2, focusing on the model of the system in use and on the criteria for indicator selection.

Concerning the role of experts in the selection of an indicator set, a practical experience is reported here in the framework of the Spanish Working Group on Spanish Coastal Sustainability Indicators (WG-SCSI). The expert group comprised ICZM experts from different institutions and organizations covering the whole coast of Spain. IH Cantabria was involved throughout the process.

The objective of the WG-SCSI was to select a small set of indicators to measure the level of sustainability of the Spanish coast based on the experience of the expert group and on the findings of the DEDUCE Project (Martí et al., 2007). The system model, built by the WG-SCSI, comprised a set of nine challenges which should be faced to improve the level of sustainability. These challenges were then used to select the most appropriate indicators and measurements. The selection process was carried out during brain-storming sessions where the experts launched different proposals to measure performance for each challenge. Even if the expert's contribution was not driven by any particular methodology, the results can be considered relevant, as a set of 21 indicators was identified (table 3.7).

According to the results of the work, the challenges identified by the WG-SCSI – and subsequently the associated indicators – are causally related: there is a strong need to highlight these causal relations so as to identify interconnected variables and improve understanding of the system's behavior.

This additional work is considered a fundamental task needed to optimize the final system.

Challenge	Indicators
1. Land use and spatial planning in the coastal zone	1.1 Land and sea covered by human activities
	1.2 Lodging capacity
	1.3 Boating capacity
	1.4 Maritime traffic
	1.5 Extraction of natural resources
2. Management of resources and wastes cycles	2.1 Water consumption
	2.2 Energy consumption
	2.3 Waste production
3. Environmental management of economic activities and industries	3.1 Implementation of Environmental Management Systems
4. Social integration and human development	4.1 Literacy rate
	4.2 Household income
5. Physical and ecological capability of coastal systems	5.1 Coastal erosion
	5.2 Artificial coastline
	5.3 Coastal and marine protected areas
6. Good state of water bodies	6.1 Ecological state of water bodies
	6.2 Chemical state of water bodies
7. Impacts of climate change on the coast	7.1 Type of coast
	7.2 Economic value of the coast
	7.3 Change in maritime climate
8. Improvement of coastal governance	8.1 Existence of coastal agreements
	8.2 Existence of coastal plans

Table 3.7. The theoretical framework (i.e. the system model) of the WG SCSI, Spain.

3.8 Discussion and conclusions

Complex, unstructured coastal problems should be dealt with using a systematic approach, under the broad framework of policy analysis, which integrates classic deterministic approaches of the physical and economic sciences with modern principles of the social sciences such as local governance, shared responsibility, community involvement and capacity building.

Coastal experts contribute their experience in specific coastal system sectors, but complex relationships are not easy to unravel. The identification and involvement of coastal stakeholders should be used to improve system understanding and as a base for further system modeling.

Four examples show the need of a systems approach to dealing with coastal issues, in many different cases: (i) in the identification and classification of stakeholders at the national level (ii) in beach engineering and management at the local level, (iii) during the preparation of regional ICZM plans in developing countries and (iv) while working with experts in the identification of coastal indicators.

In these examples, different techniques have been revised, tested or developed from scratch:

The hydra model for stakeholder identification was tested at the Spanish national level (section 3.4), the balanced scorecard was applied to support beach-management decisions in Italy (section 3.5), and participatory factsheets were used to collect data, information and perceptions of local stakeholders in Egypt (section 3.6).

All these experiences are brought together to provide a framework for coastal system exploration and to provide a broad picture of the system. The contributions of experts and stakeholders have proved to be fundamental for the creation of a broad picture of the system which includes all relevant aspects. On the other hand, the identification of the issues at stake and of the corresponding variables is not straightforward: participatory system techniques should be used to design system models which capture all the relevant aspects (components and relationships) to be taken into consideration, and to translate them into indicators.

This problem is addressed in chapter 4.

CHAPTER 4 – DRAFTING MODELS OF COASTAL SYSTEMS: A SYSTEMS THINKING APPROACH

4.1 Introduction

The purpose of this chapter is to adapt and test the systems thinking approach to identify issues and variables to be used to build sets of indicators for ICZM. This approach will be used in different cases to improve and adapt the methodology to the study of complex coastal systems.

Systems thinking, presented in chapter 2, provides practical tools to solve real problems while maintaining the systems approach as a central paradigm: it represents a way of translating holism into action.

The interaction within groups of people (experts and/or stakeholders) is central to the identification of key issues, variables and causal relationships - the model of the system we are aiming at- . A participatory approach is therefore proposed and applied using different techniques in this chapter, namely hexagon clusters, participatory causal matrices (PCM) and causal loop diagrams.

This chapter is divided as follows:

- Section 4.2 introduces systems thinking as a practical approach to improve system understanding and to identify the components and relationships of a given system.

- Section 4.3 analyzes the idea of mental models, one of the systems thinking paradigms, representing the picture of reality in the stakeholders' (or experts') minds.

- Section 4.4 introduces group model building techniques to design shared mental models of a given system.

- Finally, sections 4.5, 4.6 and 4.7 report three case studies where systems thinking and group model building techniques are applied and substantially improved to build models for the system and to identify critical issues and variables based on stakeholders' contributions.

The methodologies, experiences and discussions reported contribute to the second research question (see section 1.2):

How can we build a model of the system based on the contribution of experts and stakeholders?

4.2. The systems thinking approach

Systems thinking was introduced in chapter 2 as a systems approach to problem-solving, a way of thinking holistically about problems and to focus on the components and relations of complex systems. Systems dynamics can be considered part of the systems thinking processes, when the systems components are translated into variables (stocks and flows) and simulations are carried out to analyze the structure and behavior of a given system (Binder et al., 2008).

Aronson (Aronson, 1998), in the overview of systems thinking, introduces some basic concepts and an example of how systems thinking can be used as a framework to improve the understanding of complex systems and see the "big picture" i.e. "to see the forest and the trees".

The example is based on pest control in agriculture: an insect eating a crop is controlled through pesticide application and a simple reductionist model would be the following, where, according to the event-oriented way of thinking, the more pesticide applied, the fewer insects will damage the crops. The minus sign represents a negative effect of the first component on the second one. (figure 4.1).

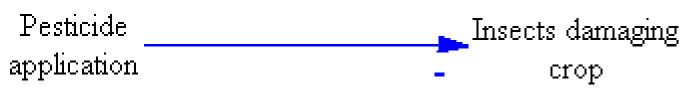


Figure 4.1. A simple reductionist model.

If we look at the system in a long-term and broader perspective we see that this only represents part of the picture: the action intended to solve the problem actually makes it worse because the model does not consider the unintended consequences (side effects) which tend to exacerbate the problem. A broader picture of the system is therefore the following, where insects A in turn control the population of insects B, resulting in a feedback loop where the more pesticide applied the greater the damage to the crop (figure 4.2).

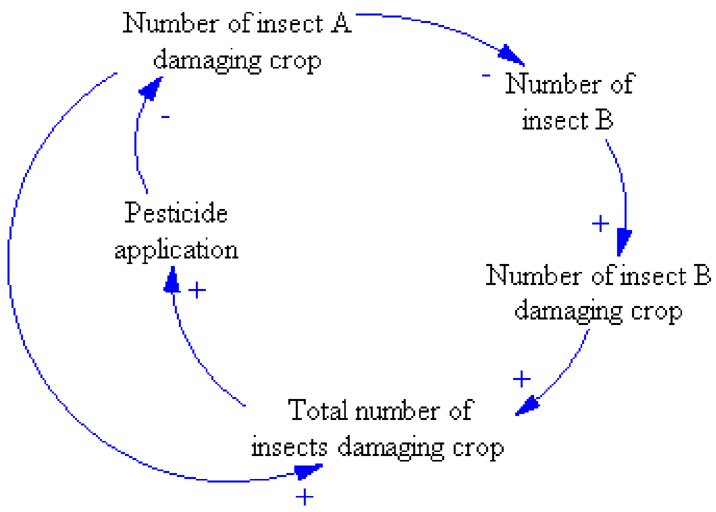


Figure 4.2. A simple holistic model using a causal loop diagram.

Seeing the bigger picture can be useful not only to understand and learn about systems but also to show stakeholders the unintended long-term consequences of their choices.

A systems thinking approach is therefore useful in multi-actor and complex systems where past solutions could become today's problems: the parts of the system affected by proposed solutions are sometimes not obvious, especially if the system is made up of many components and complex relations.

Systems thinking can be therefore used as a general framework to improve systems learning and understanding, to specify multiple stakeholders' mental models of their surrounding environment.

A formal step by step approach for systems thinking is proposed by Cavana (Cavana et al., 2000) who divides the process into three parts:

1. Problem structuring – identification of the area of concern and of the general objectives, taking into account different stakeholders. Collection of preliminary information and data including reports, policy documents, previous studies.
2. Causal loop modeling – conceptual models of the system based on shared mental models identified during the previous phase. The issues identified

previously are translated into variables and related to each other using feedback loops.

3. Dynamic modeling – causal loop models are translated into quantitative diagrams using stocks and flows (this step is formally part of systems dynamics methodologies). Simulations using dedicated software allow the identification of behavior over time and of the key system variables, to be used as leverages to address system behavior or redesign the system's structure.

While the first two steps can be considered part of a systems thinking approach, the third one enters the field of systems dynamics simulations.

The following sections are focused on the first two steps, i.e. how to structure the problem and identify the system's components and how to build causal loop diagrams using a participatory approach (group model building).

4.3 Mental models

A Mental model is a representation of reality in a stakeholder's mind.

One of the challenges of the systems thinking approach is to improve system understanding to address wrong mental models and to build shared mental models of a given system. In Senge's masterpiece "The Fifth Discipline" (Senge, 1990) four core disciplines are seen as the pillars of organizational learning: "Personal Mastery", "Shared Vision", "Team Learning" and "Mental Models". "Systems Thinking" is the fifth discipline, the conceptual cornerstone that underlies all the learning disciplines.

The following scheme (figure 4.3) illustrates how mental models work: stakeholders' "selective observations" of a given "system" shape their "mental models". Stakeholders "expectations" of the system's performance stimulate changes in their "behavior", with the objective of getting the best out of the "system".

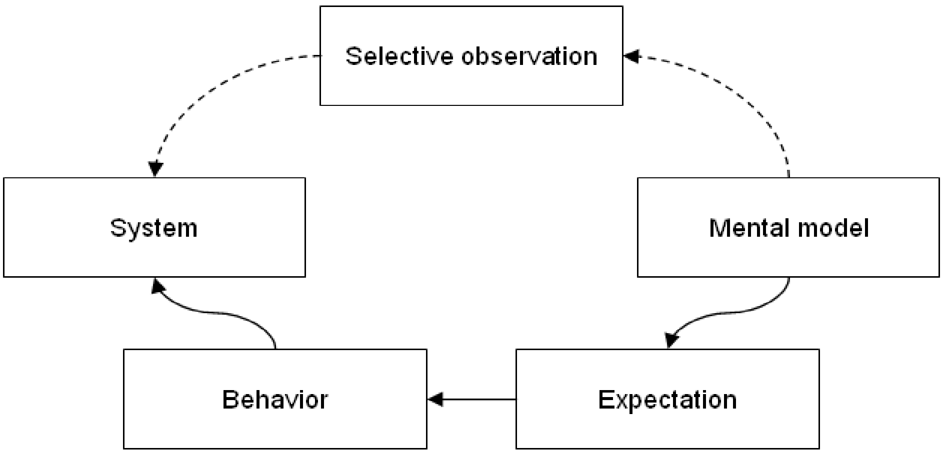


Figure 4.3. A simple scheme of a mental model at work (adapted from Hjorth et al., 2006).

Clearly, acting on a system based on a wrong mental model can bring important unintended consequences: a recent article by Sterman in Science magazine (Sterman, 2008) reports a good example of the risk of poor or wrong communication in the consolidation of wrong mental models of climate change. In this case, the erroneous belief that stabilizing emissions would quickly stabilize the climate supports wait-and-see policies but violates basic laws of physics. As Sterman says, a wait-and-see approach works well in simple systems: "we can wait until the teakettle whistles before removing it from the flame because there is little lag between the boil, the whistle, and our response". Long delays in the climate's response to anthropogenic forcing means wait-and-see policies will not work. In this context, wrong mental models and poor understanding can drive decision-makers to implement poor policies with little effect on the real problem: in climate change there are substantial delays in every link of a long causal chain, stretching from the implementation of emission abatement policies to emission reductions to changes in atmospheric greenhouse gas concentrations…when the causal chain reaches global warming, it could be too late.

Mental models are therefore quite enduring structures of the internal representation of a real system, shaped by the role of actors in a social system, their previous experience and cognitive biases (Pahl-Wostl, 2007). These models should be corrected if they are factually wrong, and a shift often requires a process of reflection, learning, design and negotiation.

4.4 Group model building

Group model building (GMB) refers to a bundle of techniques used to construct systems models, working directly with key stakeholders or experts (Andersen et al., 2007), with the objective of specifying mental models and to build a shared mental model based on their contribution, addressed by systems analysts.

This technique can be used at different scales, as complex interactions in environmental decisions exist while evaluating the impact of a single project, the environmental assessment of a plan, or the development of theoretical sustainability frameworks. GMB is especially relevant when dealing with the so-called post-science paradigm, when facts are uncertain, values in dispute, stakes high and decisions urgent (Antunes et al., 2006). This technique is particularly suited to address ill-defined strategic issues, often labeled messy problems, i.e. situations in which there are large differences of opinion on the problem, or even on the question of whether or not there is a problem (Vennix, 1999).

Group model building is being applied to many areas of knowledge, especially when stakeholders play a relevant role in the identification of key issues.

For example, Elias brings together stakeholders to identify key issues and variables for a large transport infrastructure problem (Elias, 2006). Richardson, on the other hand, provides an overview of the roles needed while working as a team during GMB (Richardson et al., 1995). Five different roles are provided (the facilitator, the modeler, the process coach, the recorder and the gatekeeper) and some can be combined to optimize the cost-effectiveness of the exercise.

Few examples of the use of mental models and group model building have been found in the ICZM literature: Santoro brings together cognitive maps to build stakeholders' mental models in a broad framework for ICZM (Santoro, 2007). Antunes on the other hand analyzes the use of mediated modeling techniques and implements a model for the Ria Formosa in Portugal (Antunes et al., 2006).

The present research identified different steps to be followed in GMB while dealing with complex coastal problems:

1. Identify the components of the system.

2. Identify key issues.

3. Identify critical variables for each key issue.

4. Build participatory causal matrices (PCM).

5. Build causal loop diagrams (CLD).

6. Build stock and flows diagrams (SFD).

7. Run dynamic simulation.

This methodological approach, built on systems thinking and systems dynamics theory, can be used to model the system's behavior and improve stakeholders' understanding of that behavior. The examples reported in the following sections are based on the first five steps:

1. The first example is a complete simulation of a theoretical model (section 4.5)

2. The second example is a simple simulation of the beach management project in section 3.5 (section 4.6).

3. The third example is based on the experience gained during the MSICZMP Project in Egypt (section 4.7).

4.5 Case study: a theoretical model

A theoretical model is used as an example to show how a group model building exercise (GMB) should work. In the model, 4 stakeholders are involved, to identify issues and variables for a given coastal system. Stakeholders are then asked to fill out participatory causal matrices (PCMs) which are finally combined to build a shared mental model. The stakeholders' contribution is finally quantified to assign importance and rank variables. Ranking can be used to reduce the set to a simplified model of the system.

4.5.1 Identification of system components

The identification of the system's components is a useful step to start thinking holistically about the system we are going to model. Components should be thought of as high level sub-systems enclosing sector issues and variables.

In ICZM projects, the coastal zone can be seen as a system made up of the following components (figure 4.4):

- Physical sub-system
- Ecological sub-system
- Social sub-system
- Economic sub-system
- Administrative sub-system

The systems components should be highlighted at the beginning of a GMB exercise to open stakeholder's minds towards an integrated and holistic vision of the coast.

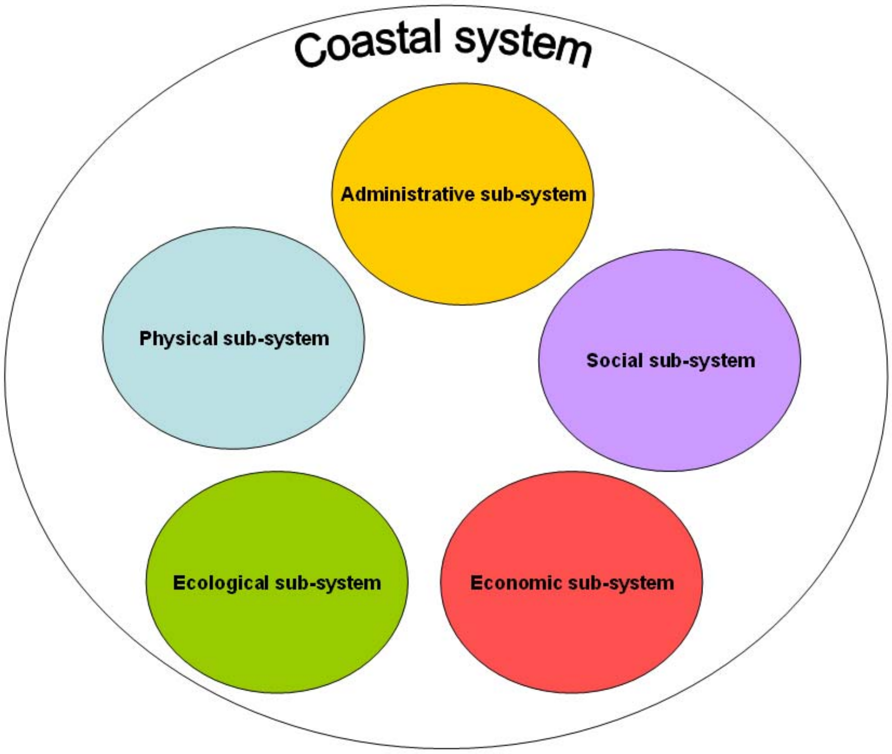


Figure 4.4. The coastal system and its sub-systems.

4.5.2 Identification of key issues and variables

Key issues represent the core of stakeholders' mental models, as they are the problems that bring stakeholders together in the exercise. The collection of preliminary information and data including reports, policy documents, and previous studies can be the base to help stakeholders identify key issues.

Facilitation tools are fundamental to collect information and optimize the identification of key issues of the coastal system. One example of a facilitation tool is the use of empty factsheets, to be filled in with information by stakeholders (Sanò et al. 2007).

The identification of key issues is fundamental to design a preliminary model of the system, to be analyzed using systems techniques or multivariate analysis. The translation of key issues into variables is not straightforward: experts and stakeholders should be asked to associate one or more variables to the issues affecting their sector of interest: a system made up of familiar variables eases shared understanding. In any case, identification of quantifiable variables is needed when a quantitative analysis is supposed to produce further results (i.e. multivariate statistics, systems dynamics).

The use of colored hexagons (Hodgson, 1992) can drive the identification of key issues and variables.

In this technique, colored hexagons for each system's components are distributed to participants who are asked to fill them in with a key issue and one or more variables to measure it. The result of the experiment is the translation of the generic coastal systems model into a model made of hexagon clusters. The result is a shared mental model of the coastal system which doesn't (yet) include hypothetical correlations and/or causal relations between key issues and/or variables.

Following our example, the hexagon clusters are used by our four stakeholders to identify twelve variables belonging to five sub-systems. (figure 4.5).

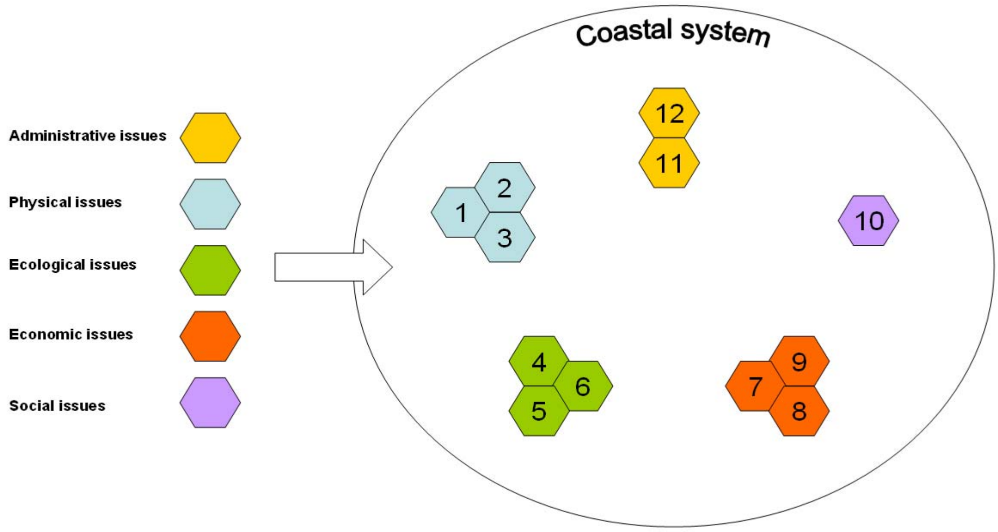


Figure 4.5. Colored hexagons are distributed between four stakeholders, who finally identify a set of 12 variables as a model of the system.

4.5.3 Participatory causal matrices and causal loop diagrams for system modeling and simplification

Participatory causal matrices (PCM) are developed in this thesis to improve the understanding of systems and to specify the mental model of each stakeholder using causal loop diagram (CLD) notation.

Following our example, the idea is to fit the previously identified 12 variables (or key issues) into a 12 x 12 matrix to explore the opinions of stakeholders concerning the (hypothetical) causal relations between them. With four stakeholders filling in the causal matrix, four matrices are obtained. The matrices are then superimposed, to build a complete matrix which reports and summarizes all the stakeholders' contributions.

Participatory causal matrices can be easily used to build CLDs by asking the following question for each variable in the first column, and moving from left to right,:

"Has variable V_i a causal relation with variable V_j?"

This is the same as saying:

"Does a change in V_i provoke a change in V_j?"

The answer to this question provides information about the existence of a hypothetical causal relationship.

If we want to add polarity (i.e. the positive or negative effect of one variable on the other) to this causal relationship, we can add to the same question:

"Does increasing V_i increase or decrease V_j?"

If the variable V_i causes an increase in V_j, then we should put a "+" sign in the cell, otherwise, if it causes a decrease, we should put a "-" sign.

A causal loop diagram can then be drawn from the matrix obtained or from the combined matrix obtained from the different stakeholders.

Going back to the example, four stakeholders were involved in a group model building exercise, with the objective of building a shared mental model of the system concerned. The preliminary result was represented by a set of 12 variables. During this exercise, the first stakeholder filled in the PCM, providing its mental model of causal relationships between variables, and finally identified 11 significant hypothetical causal relationships between the variables (see table 4.1).

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
V1		-					-					
V2									+			
V3						+						
V4												
V5										-		
V6		-							-			
V7												
V8		-										
V9						+						
V10												
V11		-										+
V12												

Table 4.1. Participatory causal matrix filled by stakeholder 1.

This matrix can be mapped using causal loop diagram notation, connecting variables with arrows (figure 4.6).

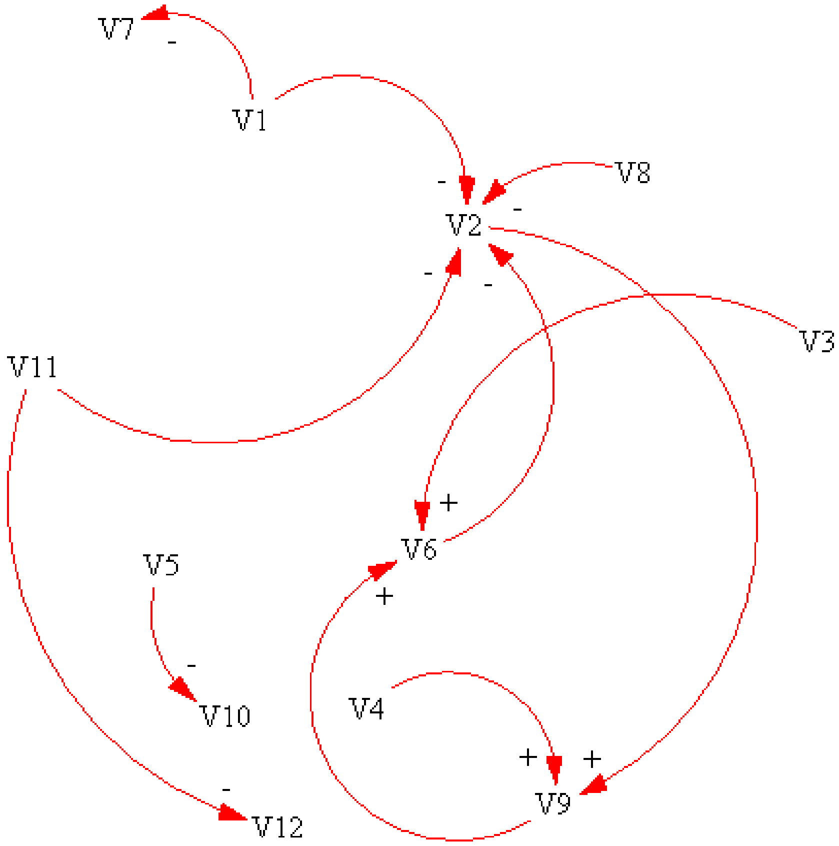


Figure 4.6. Causal loop diagram based on the causal matrix filled in by stakeholder 1.

The above matrix and causal loop diagram are based on the opinion of one stakeholder. The causal matrices of stakeholders 2, 3 and 4 are reported as follows (tables 4.2, 4.3 and 4.4).

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
V1		-										
V2									+			
V3												
V4	+								+			
V5												
V6												
V7												
V8		-										
V9				+		+						
V10												
V11												+
V12												

Table 4.2. Participatory causal matrix filled by stakeholder 2.

	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**
V1		-	-		+							
V2												
V3												
V4												
V5												
V6									-			
V7												
V8												
V9	+				+							
V10												
V11							-					
V12												

Table 4.3. Participatory causal matrix filled by stakeholder 3.

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
V1		-				+	-					
V2									+			
V3						+						
V4	+								+			
V5												
V6			+						-		+	
V7												
V8		-										
V9				+		+						
V10												
V11												
V12												

Table 4.4. Participatory causal matrix filled by stakeholder 4.

Grouping the contribution of four stakeholders (by summing up the number of causal relationships) gives information about the importance of each variable V_i in terms of importance in rows I_x and importance in columns I_y (for example, V1 has I_x=9 and I_y=3) (table 4.5).

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	Importance I_x
V1		----	-		++		--						9
V2									+++				3
V3						++							2
V4	++								++				4
V5										-			1
V6		-	+						--		+		5
V7													0
V8		---											3
V9	+			++		++++							7
V10													0
V11		-					-					+	3
V12													0
Importance I_y	3	9	2	2	2	6	3	0	7	1	1	1	37

Table 4.5. Shared participatory causal matrix based on the causal matrices filled by each of the four stakeholders.

A causal loop diagram better represents the shared mental model produced by the exercise. In this diagram the red arrows represent the causal relations identified by stakeholder 1, the blue arrows added by the contribution of the other three stakeholders: the mental model shared by the four stakeholders is more complex than what the first stakeholder had in mind (figure 4.7).

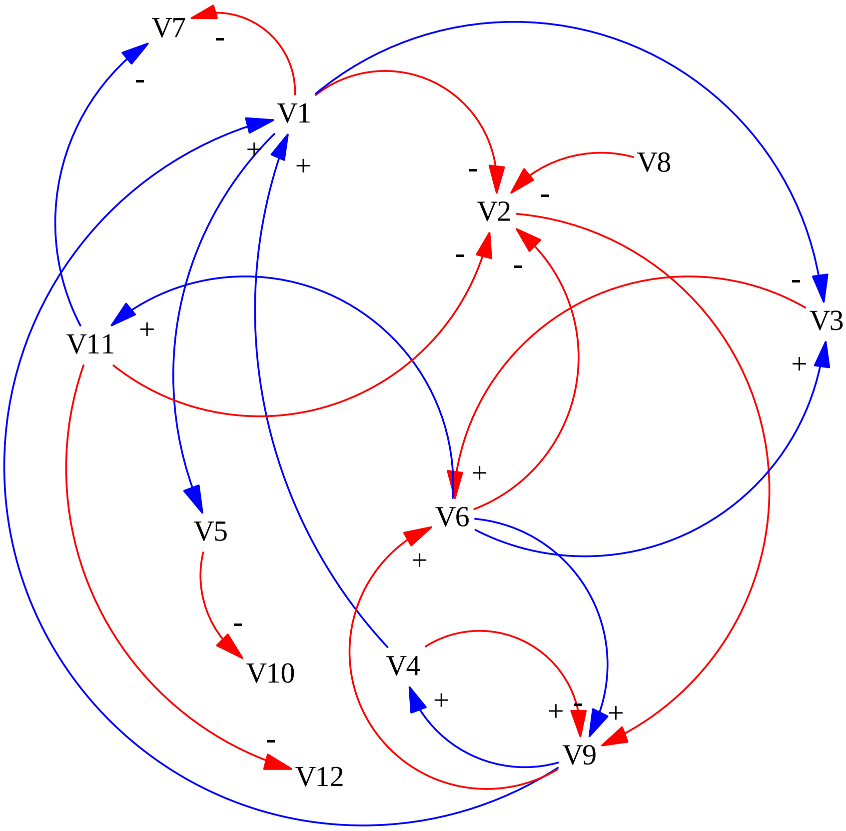


Figure 4.7. Causal loop diagram based on the shared participatory causal matrix.

More information regarding the importance and the level of influence of each variable V_i is given by the number of outgoing arrows N_{iout}, i.e. the number of variables affected by changes in V_i (for example, V1 has N_{1out}=4).

The total importance I_i is given by the sum of the number of relations existing per variable V_i.

The multiplication of the total importance I_i by the number of outgoing arrows N_{iout} is the ranking R_i of variable V_i (table 4.6):

$$R_i = (I_{ix} + I_{iy}) \times N_{iout} = I_i \times N_{iout}$$

	Importance I_x	Importance I_y	Total importance $I = (I_x+I_y)$	Number of outgoing arrows N_{out}	Ranking $R=I*N_{out}$
V1	9	3	12	4	48
V6	5	6	11	4	44
V9	7	7	14	3	42
V11	3	1	4	3	12
V4	4	2	6	2	12
V2	3	9	12	1	12
V3	2	2	4	1	4
V5	1	2	3	1	3
V8	3	0	3	1	3
V7	0	3	3	0	0
V10	0	1	1	0	0
V12	0	1	1	0	0
Total	37	37	74		

Table 4.6. Results of the experiment carried out by a theoretical group of four stakeholders.

This simple example resulted in the identification of 4 groups of 3 variables, ordered in terms of importance and causality assigned by stakeholders. These results can be used for different purposes:

1. Simplify the system by selecting a cut-off point based on the information provided.

2. Select the group representing the most important variables as a preliminary set of indicators (data reduction).

4.6 Case study: beach management in Finale Ligure, part II

The following example is based on practical experience from coastal restoration projects in the Mediterranean. The example uses the Finale Ligure coastal restoration project (section 3.5) as a base to apply the group model building approach described in section 4.5. The exercise is based on a desk simulation, and no real stakeholder was actually involved.

4.6.1 Case description

In this case the client (the problem owner) is a coastal municipality, directly responsible for the maintenance of local beaches. As numerous conflicts often arise as the unintended consequence of decisions regarding beach maintenance, the municipality recognizes the need for a more integrated and systems approach in solving coastal problems. The stakeholders identified are invited to attend a participatory workshop designed to address coastal problems.

In this simplified exercise, the stakeholders are asked to identify only one issue, one objective and one quantifiable variable per issue/objective (table 4.7).

Number	Actor	Problem	Objective	Variable	Units of measurement
1	Municipality	Beach erosion	Beach protection	Volume of sand for nourishment	m^3
2	Beach resorts association	Loss of Beach area	Beach maintenance	Beach area	m^2
3	Tourists	Dust in sand	Sand quality	% of fine sediments	%
4	Environmental agency	Water pollution	Water quality	Water turbidity	NTU
5	Conservation NGO	Seagrass loss	Seagrass quality	Density of seagrass meadow	Leaves*m^2
6	Fishermens' association	Fishing catch decrease	Maintenance/improvement of fish catches	Weights of fishing catches	Tons/year
7	Port authority	Channel navigability	Navigation safety	Navigation channel variability	Depth (m)
8	Surfers' association	Worsening Surfing conditions	Improvement of the reef	Number of surfing days	Days/year

Table 4.7. Stakeholders, issues, objectives and variables for a coastal project in the Mediterranean.

In the real world, the system works as follows: sand from the navigation channel of a port is used for beach nourishment.

Sand drift tends to fill the port navigation channel, and periodical dredging is needed to maintain navigability.

Sand for nourishment dredged from the channel contains a percentage of fines which can be controlled technically during dredging. The quantity of fines affects water turbidity, which in turn in the longer term affects the health of a seagrass meadow, a nursery area for fisheries.

Beach nourishment can directly affect the seagrass meadow as well, covering its upper limit.

Finally, surfing conditions normally improve with beach nourishment, as the shape and volume of the outer sand bars rely on sand availability.

4.6.2 The PCM and the CLD

The exercise is based on a desk simulation, and no real stakeholder was actually involved. Despite this, a draft model using the PCM to collect the contributions of eight stakeholders can be represented as follows (table 4.8):

	Volume of sand for nourishment	Beach area	% of fine sediments	Water turbidity	Density of seagrass meadow	Fishing catches	Depth of navigation channel	Number of surfing days	Importance I_x
Volume of sand for nourishment		+++++	+++					+	9
Beach Area					-				1
Quantity of fine sediments		-		++++	--	--			9
Water turbidity					--				2
Density of seagrass meadow						---			3
Fishing catches									0
Depth of the navigation channel	+++								3
Days of good surfing conditions									0
Importance I_y	3	6	3	4	5	5	0	1	

Table 4.8. Shared participatory causal matrix based on the desk simulation of a coastal project in the Mediterranean.

The same matrix is then translated into a Causal Loop Diagram (figure 4.8)

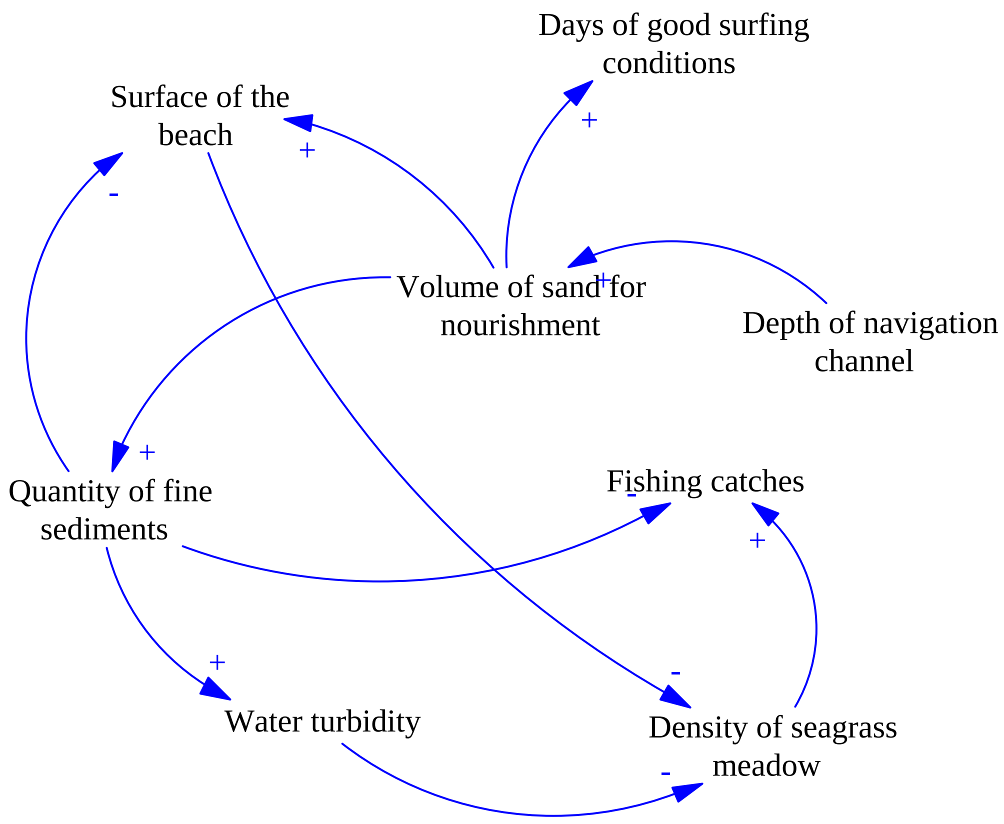


Figure 4.8. Causal loop diagram based on the shared participatory causal matrix for a coastal project in the Mediterranean.

4.6.3 Results

The results of the experiment are reported as follows, where I_{ix} and I_{iy} are the sums of the importance given to each variable V_i by stakeholders in the causal matrix, N_{iout} is the number of outgoing arrows per issue and R_i is the final ranking given to the variables (table 4.9):

$$R_i = (I_{ix} + I_{iy}) \times N_{iout} = I_i \times N_{iout}$$

	Total in rows I_x	Total in columns I_y	I_x+I_y	N_{out}	R
Volume of sand for nourishment	9	3	11	3	33
Beach area	9	6	15	1	15
Percentage of fine sediments	1	3	4	3	12
Density of seagrass meadow	2	5	7	1	7
Water turbidity	3	4	7	1	7
Depth of the navigation channel	3	0	3	1	3
Fishing catches	0	5	5	0	0
Number of surfing days	0	1	1	0	0
TOTAL	27	27	54	10	

Table 4.9. Ranking of variables based on the desk simulation of a coastal project in the Mediterranean.

The table shows how the first three variables, "Volume of sand for nourishment", "Beach area" and "Percentage of fine sediments" are critical for the whole system.

These results of the example seem obvious at first sight, but the objective is to demonstrate that it is possible to identify critical issues and/or variables for the system based on stakeholders' knowledge, with little help from coastal experts.

Results of such experiments are not so obvious when the system is unknown and stakeholders have different visions regarding the source of the problems (see next example, section 4.7).

4.7 Case study: The Matruh-Sallum ICZM Plan (MSICZMP), Part II

The following example is based on the MSICZMP Project (section 3.6) carried out by IH Cantabria (IH Cantabria, 2007). In this case three experts involved in the project were asked to participate to the exercise.

4.7.1 Case description

The Matrouh Sallum ICZM Plan (MSICZMP) is an ICZM cooperation project promoted by the Spanish Cooperation Agency AECID and executed by IH Cantabria and the Egyptian Environmental Affairs Agency. A diagnosis of the coastal system was carried out during phase I of the project (2006-2007) while the ICZM plan is the main output of phase II (2008-2009). This example is based on the result of the diagnosis (coastal profiling) carried out by the expert team during phase I and the public participation workshop designed to collect information and perceptions regarding key coastal issues for the region.

4.7.2 The system components

A vision of the coastal system including physical, ecological, social, economic and administrative components provides a broad, holistic frame for the identification of key issues. Without a doubt, one issue can belong to one or more sub-systems, as many of them are the result of complex interactions between components. This does not play down the importance to the system's components approach, as the results of the participatory workshop (where stakeholders were asked to fill in participatory factsheet for each system component, see section 3.6) confirm that it helps to drive stakeholders in the identification of key issues and improve general understanding of the whole system.

4.7.3 Identification of key issues

The identification of key issues is based on the integration of the expert teams' knowledge with the perception and understanding of the local communities.

During Phase I of the project, the expert team was asked to prepare thematic reports (profiles) on the physical, ecological, socio-economic and administrative sub-systems. The same expert team joined local stakeholders in a public participation workshop designed to identify key issues for the area.

The following table reports the main issues. In this case, coastal issues are used instead of variables for the whole procedure (table 4.10).

System component	No.	Issue	Description
Physical	1	Coastal erosion on beaches	Most of the beaches along the coast suffer erosion and floods under extreme conditions.
	2	Sea level rise and climate change	Climate change is probably going to worsen the current situation. The probability of extreme marine events is going to increase.
	3	Flash floods	Small dried riverbeds (wadis), commonly used for agriculture, are subject to periodic floods.
	4	Coastal dunes degradation	Erosion of coastal dunes is mostly related with coastal development and dune exploitation for the building industry.
	5	Freshwater shortage	Freshwater shortage is related with overexploitation for agriculture, human use and salt intrusion.
Ecological	6	Marine ecosystem degradation	Marine ecosystems are degraded by activities associated with indiscriminate fisheries and water discharge from coastal towns.
	7	Overfishing from trawlers	Trawling form big fishing boats is considered an unsustainable activity by local fishermen.
	8	Solid waste disposal	One of the main issues for the earth's environment is related to the disposal and discharge of solid wastes.
	9	Wastewater discharges	Wastewater is discharged at sea and near the villages, with high risks of water source pollution.
	10	Natural reserve implementation	There is a strong need to protect special areas along the coast by declaring land and marine natural reserves.
Economic	11	Urban sprawl along the coast	The coastal area is subject to urban sprawl for tourism on the first 60 km of the coast.
	12	Development of high quality tourism	Tourism development in the region should be based on sustainable development principles
	13	Agricultural development	Agricultural development is one of the main issues for the area, water availability being one of the main limiting factors for its sustainability.
	14	Aquaculture development	Aquaculture development is seen as one possible alternative to fisheries and a new sector for economic development
	15	Industrial development	Industries are considered important sources of income and employment for the local population.
	16	WWII Mine fields	Information on minefields should be made available, to define exactly the area affected by this severe problem.
	17	Communications and accessibility	Development of an international airport and the improvement of roads and highways is a development priority .
Social	18	Participation of women in society	The involvement of women in social life and as a working force for future development is a long-term issue which could be solved through education.
	19	Local traditions	New forms of development should respect and understand local traditions.
Administrative	20	Military zones	Devolution of the coastal land controlled by the military could improve spatial development.

Table 4.10. The selection of coastal issues (the system model) based on the results of the coastal diagnosis of the MSICZMP Project.

4.7.4 The PCM and the CLD

The following causal matrix (table 4.11) was built following an exercise by a small expert team: three team experts independently filled in one causal matrix, and a shared matrix was then built, following the methodology set out in section 4.5.3.

HAS A DIRECT RELATION WITH / IS THE CAUSE OF ---->	Coastal erosion on beaches	Sea level rise and climate change	Flash floods	Coastal dune degradation	Freshwater shortage	Marine ecosystem degradation	Overfishing by trawlers	Solid waste disposal	Wastewater discharges	Natural reserve implementation	Urban sprawl along the coast	Development of high quality tourism	Agricultural development	Aquacultural development	Industrial development	WWII Mine fields	Communications and accessibility	Participation of women in society	Maintenance of local traditions	Military zones	I_x
Coastal erosion on beaches											-	--									3
Sea level rise and climate change	+++		+		+++					+			--								10
Flash floods	-					++			++		-		--			++	-				11
Coastal dune degradation	+++									+	-	-					-				7
Freshwater shortage									-		-	--	---		---						10
Marine ecosystem degradation	+						+			+		-							--		6
Overfishing by trawlers						+++				+									-		5
Solid waste disposal												-									1
Wastewater discharges						+++						-									4
Natural reserve implementation				-		--	-	---	-		---	+++							-		15
Urban sprawl along the coast	++			+++	+			++	+++			-	-						--		15
Development of high quality tourism				-													++		+		4
Agricultural development					+			++	+		-				++			+	+++		11
Aquacultural development						+++									++						5
Industrial development						+++		++	++	-											8
WWII Mine fields											--	--	---		--		--		-	+	13
Communications and accessibility											+++	+++	++	++	++	-					13
Participation of women in society																			++		2
Local traditions										+		+	+++					-			6
Military zones				-						-	---	--	---		-		-		-		13
I_y	10	0	1	6	5	16	2	9	10	7	16	20	19	2	12	3	7	2	14	1	162

Table 4.11. Shared Causal Matrix based on a simulation carried out involving three experts.

Based on the causal matrix above, a causal loop diagram has been built, mapping the shared mental model and the causal relationships between the key issues (figure 4.9).

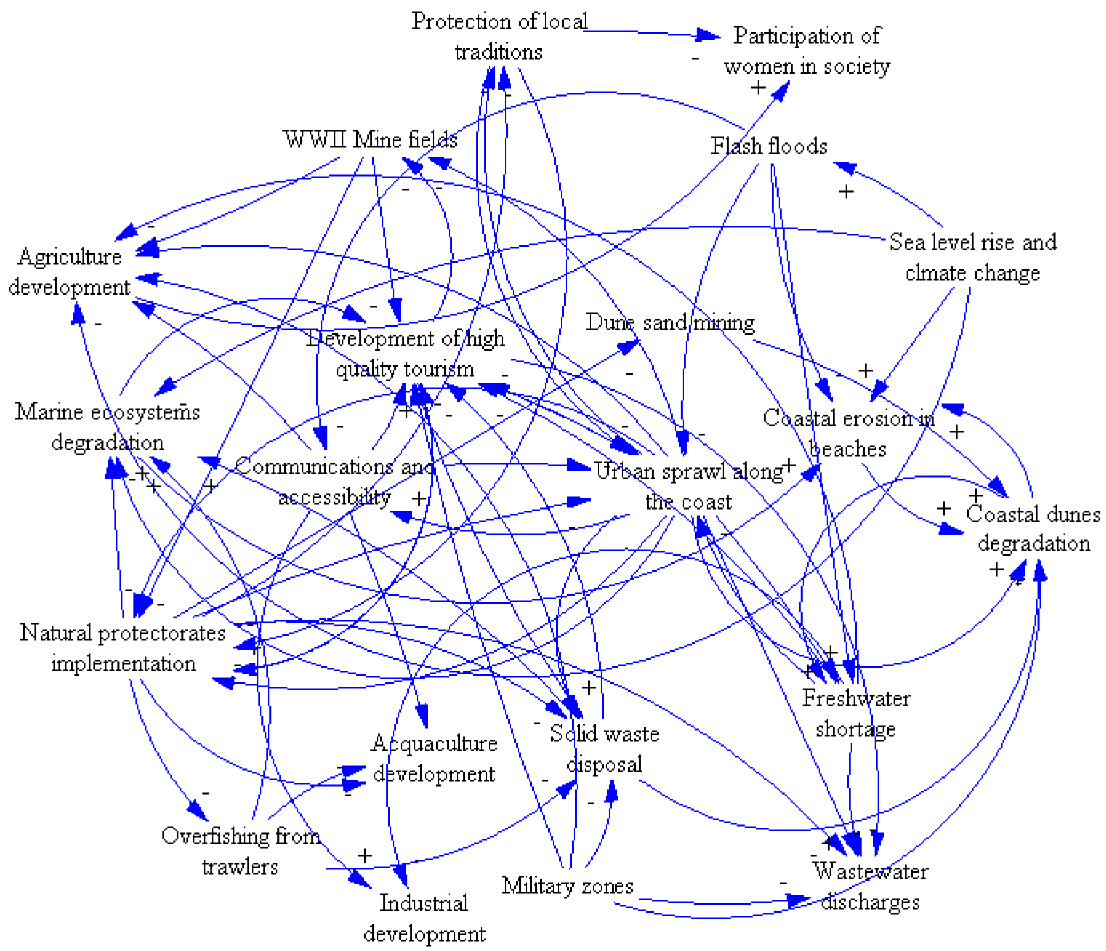


Figure 4.9. Causal loop diagram based on the shared participatory causal matrix for the MSICZMP Project.

4.7.5 Results

The results from that analysis are reported on the following table (table 4.12), where each issue's ranking R_i is calculated using the combination of the overall importance given by the participant to the participatory exercise and the number of outgoing arrows:

$$R_i = (I_{ix} + I_{iy}) \times N_{iout} = I_i \times N_{iout}$$

Issue	I_x	I_y	N_{out}	R
Urban sprawl along the coast	15	16	8	248
Agricultural development	11	19	7	210
Natural reserve implementation	15	7	8	176
Communications and accessibility	13	7	6	120
WWII Mine fields	13	3	7	112
Military zones	13	1	8	112
Marine ecosystems degradation	6	16	5	110
Local traditions	6	14	5	100
Flash floods	11	1	7	84
Industrial development	8	12	4	80
Freshwater shortage	10	5	5	75
Development of high quality tourism	4	20	3	72
Coastal dune degradation	7	6	5	65
Sea level rise and climate change	10	0	5	50
Wastewater discharges	4	10	2	28
Coastal erosion on beaches	3	10	2	26
Overfishing by trawlers	5	2	3	21
Acquaculture development	5	2	2	14
Solid waste disposal	1	9	1	10
Participation of women in society	2	2	1	4
Total	162	162	94	30456

Table 4.12. Ranking of variables for the MSICZMP Exercise.

The results show different clusters of issues based on the shared mental model of the system built up by the participants. "Urban sprawl on the coast" was considered by all participants in the exercise as one of the most important drivers of the systems but other issues emerged such as "Agricultural development" and "Natural reserve implementation".

4.8 Discussion and conclusions

This chapter applies the systems thinking approach and develops and improves group model building techniques throughout three practical examples in coastal management, with the aim of demonstrating how group interactions can address system modeling.

All the methodologies proposed used groups of people (stakeholders and experts) as their main source of information for modeling. The methodologies drive the group towards a model of the system based on consensus: a shared mental model. This model is made up of variables and relationships identified by the group using participatory tools such as participatory causal matrices and causal loop diagrams.

The identification of the system's components is considered a first step to building a shared model of the system; the components are identified using a systems approach which considers the coastal system to be made up of different sub-systems (e.g. physical, ecological, economic, social and administrative).

Subsequently, experts and stakeholders should be asked to identify key issues and one or more corresponding variables per sub-system using participatory techniques such as hexagon clusters; the result is a list of variables (or issues) based on group interaction.

The participatory causal matrix was developed in this thesis to help model complex systems using contributions of experts and stakeholders. With this tool, the participants in the group model building exercise should be asked to identify causal relationship between variables. PCMs are then used to map the system's causal relationships using causal loop diagrams to represent the system model.

Stakeholder contribution should be finally translated into a ranking of variables: the level of recurrence of each variable is multiplied by the number of variables affected; the results give information about the importance of each variable and its effect on the overall system.

This ranking can be used to select a number of variables $p<n$ to be used as a preliminary set of indicators for further analysis using multivariate techniques (see chapter 5).

The GMB approach has been shown to be useful to build a model of the system and improve system understanding, group learning and consensus building among participants. The use of the GMB approach in real situations, when stakeholders are invited to participatory workshops and asked to give their contribution to build a shared mental model for the system, will be applied during Spring 2009 to the MSICZMP Project in Egypt. One of the problems which can emerge during this GMB exercise arises from difficulties met by the group while filling out a complex matrix made up of many different issues, where only direct causality should be highlighted.

CHAPTER 5 – MULTIVARIATE ANALYSIS OF COASTAL SYSTEMS: DELIVERING CRITICAL INDICATORS

5.1 Introduction

Chapters three and four were centered on the exploration of coastal systems to focus on the real problems of the system from different perspectives, to deliver a preliminary set of indicators for the system. This chapter deals with techniques which can be used to analyze the system's variables using multivariate statistics to explore redundancies and identify the variables which provide the largest amount of information, to be used as indicators.

The approach in this chapter follows some of the methodologies proposed by OECD (Nardo et al., 2005), which offers a general framework for the construction of indicators based on the following steps: (i) critical revision of the system model, (ii) data collection, (iii) imputation of missing values and (iv) multivariate analysis.

A multivariate analysis technique, principal components analysis (PCA), was chosen for analysis of different sets of variables previously identified by experts and stakeholders, using two case studies as examples: the DEDUCE database and the COSVA database.

While different techniques are available to analyze the system model and carry out simulations (namely system dynamics, principal component analysis, factor analysis and structural equation modeling) PCA was chosen as it ensures orthogonality (independence) between the variables analyzed, and groups them into clusters of variables which can be further explored separately. Moreover, the objective of PCA is to identify the variables of a set which account for the largest amount of information in terms of its variance.

The correct use of PCA relies on data availability: missing values analysis (MVA) techniques were also used to fill the gaps in the available databases. In this context, the first part of this chapter is dedicated to the problem of missing values and the techniques available for imputation, a preliminary step for any multivariate analysis.

The mathematical foundations of PCA are also reported, to provide the conceptual instruments to understand the methodology: PCA can be used to identify groups of variables which have the same patterns of behavior while, at the same time, the results can be used as a statistical approach for variable selection and weighting.

The DEDUCE database was used to test both MVA and PCA. Considering the initial gaps in the available datasets used in the analysis, an extended imputation of missing values was found to be fundamental to proceed with the application of multivariate techniques. PCA was then used to identify the principal components which account for the highest amount possible of information, and to assign weights to the variables identified.

The Cantabria Oil Spill Vulnerability Atlas (COSVA) was used as a second test for PCA, to explore redundancies in the initial dataset.

This chapter is structured as follows:

- Section 5.2 links the previous chapters on the use of the systems approach to identify issues and variables with this one, where multivariate statistics are applied to analyze the system.
- Section 5.3 and 5.4 deal with the problem of data availability and the use of missing value analysis technique to fill incomplete datasets.
- Section 5.5 introduces principal component analysis and its mathematical meaning.
- Sections 5.6 deals with the techniques used to assign weights and aggregate variables to build composite indicators based on statistical models.

- Finally, sections 5.7 and 5.8 report two case studies (The DEDUCE Database and the COSVA Database) used to demonstrate the potential of PCA for data reduction.

The methodologies, experiences and discussions reported contribute to answering the second research question (section 1.2):

How can we identify the variables which best describe the system to use them as coastal indicators?

5.2 System model as a starting point for multivariate analysis

Chapters 3 and 4 showed how to develop problem-oriented models of coastal systems combining expert knowledge, public perception and systems thinking.

Based on this approach, the contribution of stakeholders and/or experts should bring in both information regarding the key issues and the corresponding variables, resulting in a system made up of *n* variables.

Causal relations between these variables can be hypothesized using experts' knowledge and stakeholders' opinions, through the use of participatory causal matrices translated into causal loop diagrams (see section 4.5.3). In data-poor systems, causal loop diagrams can be translated into stock and flow diagrams to carry out SD simulations (Binder, 2008). If real data are available, the model can be further explored using multivariate statistics.

Multivariate statistics techniques such as principal component analysis (PCA) can be used to analyze the structure of a system. Moreover PCA can be used as a quantitative strategy to reduce the number of variables which compose the model as a more manageable set accounting for most of the variance of the original data, a useful strategy when dealing with large and expensive datasets. Building a composite indicator to monitor the state of the overall systems with respect to goals can also be an option when communication with the general public and policy makers can place the problem focus at the centre of a debate.

In sum, a well defined model of the system is the starting point to improve system understanding, to explore relationships between variables, to reduce the number of variables while retaining as much information as possible and to deliver a composite indicator which can improve communication with the general public.

5.3 Data availability as a limiting factor

Statistics rely completely on data availability, but data collection can be a long and expensive process, especially in developing countries where no statistics offices are running, data are hidden in sector offices or they may not even exist. This is often an issue in more developed countries too, when the variables identified for the system are not normally used by statistics offices or they have been collected with low resolutions in time and space.

Given a model for a coastal system, multivariate statistics can be applied if many different cases are available. Cases can be either places (stations, coastal municipalities, coastal regions, beaches) or time intervals (years, months, days) or a combination of both. When dealing with "places", in principle it is always possible to collect data, but in the case of time series, it is often impossible to collect all the data needed for a system model: this problem should be considered when choosing between different variables.

Even when data exist, there can be gaps in the time series due to random missed values or the time resolution of the process we want to analyze. In any case, multivariate analysis relies on the existence of data.

It is not possible to use this technique for structure exploration, data reduction or to build composite indicators if the initial dataset is not complete.

Despite this, gaps can be filled using missing values imputation techniques.

5.4 Imputation of missing values

Databases and datasets are often incomplete. Sometimes those responding to a survey are not available or do not wish to answer a specific question. Sometimes environmental measurement fails randomly or due to extreme weather conditions. Other times the agencies responsible run out of funds, and were unable to collect data in a particular year.

As an example, the DEDUCE database is characterized by many gaps for variables collected at different intervals or randomly missed records: imputation of missing values was therefore necessary to proceed with further analysis.

Imputation of missing values (alternatively called imputation of missing data) is a useful strategy to deal with incomplete datasets or to prepare datasets for further analysis. Multivariate analyses can only be carried out on complete datasets, either collected directly or derived using imputation techniques.

According to Little and Rubin (Little & Rubin, 1987), data can be missed in a random or non-random fashion:

- Missing Completely at Random (MCAR): Missing values do not depend on the variable of interest or any other observed variable in the dataset (example: a gap in the measurement of wave height time series using a wave gauge in good weather conditions).

- Missing at Random (MAR): Missing values do not depend on the variable of interest, but can condition the data availability of other variables (example: a gap in wave height measurement affects the calculation of the mean energy flux).

- Not Missing at Random (NMAR): Missing values depend on the values themselves (e.g. fishing vessels seldom report data regarding the income generated by their activity).

An extended array of techniques are available for the imputation of missing values, and the literature on the subject is extended and is developing rapidly. Summaries of the techniques available are provided by different authors (Little & Rubin, 1987; Junninen et al., 2004; Nardo et al., 2005).

A practical example of data imputation is reported in section 5.7.3, where different data imputation techniques are confronted for the DEDUCE database. Spline interpolation is finally used to fill gaps in the time series.

5.5 Principal components analysis (PCA)

Principal components analysis is performed when we want a simpler representation of a set of variables. PCA mathematical foundations are introduced here to understand the potential of this technique in the analysis of large sets of coastal data such as the DEDUCE datasets or the COSVA datasets, the two case studies in this chapter.

PCA is a method of transforming the original variables into a set of new, uncorrelated variables, called the principal components. Each principal component is a linear combination of the original variables and the measure of the amount of information conveyed by each principal component is its variance. PCA was chosen for the analysis as it ensures orthogonality (independency) between different groups of variables and provides information about the relative importance of each variable within the group in terms of the amount of variance it accounts for.

Introduced by Hotelling in 1933 (Hotelling, 1933) in education testing, PCA has been used for different purposes (data reduction, data structure analysis, weighting variables, etc.) and different fields (health, psychology, environmental sciences, engineering).

Some relevant experiences in PCA include the construction of composite indicators for regional economics (Peters et al., 1970), the analysis of images in remote sensing (Lasaponara, 2006), the analysis of environmental variables (Shi et al., 2004; Bastianoni et al., 2008) or the reduction of the number of variables (Sardá et. al., 2005).

The idea of PCA is to explain as much variance as possible of an original set of variables $X_1, X_2 \ldots X_n$ with a few linear combinations of the original variables, called the principal components, $C_1, C_2, \ldots C_p$, where $p < n$:

$$C_1 = a_{11}X_1 + a_{12}X_2 + \ldots a_{1n}X_n$$

$$C_2 = a_{12}X_1 + a_{22}X_2 + \ldots a_{2n}X_n$$

…

$$C_n = a_{1n}X_1 + a_{1n}X_2 + \ldots a_{1n}X_n$$

In practice, performing PCA on *n* sets of variables returns *n* components (as much as the number of the initial variables) with the ultimate aim of retaining only the $p < n$ components which account for as much variance as possible (usually > 80%) in the set of variables: these are the principal components.

PCA deals with finding the eigenvectors and eigenvalues of the covariance matrix C for the datasets X_1, X_2,... X_n:

$$C = \begin{pmatrix} \mathrm{cov}(X_1, X_1) & \mathrm{cov}(X_1, X_2) & \dots & \mathrm{cov}(X_1, X_n) \\ \mathrm{cov}(X_2, X_1) & \mathrm{cov}(X_2, X_2) & \dots & \mathrm{cov}(X_2, X_n) \\ \dots & \dots & \dots & \dots \\ \mathrm{cov}(X_n, X_1) & \mathrm{cov}(X_n, X_2) & \dots & \mathrm{cov}(X_n, X_n) \end{pmatrix}$$

Where:

$$\mathrm{cov}(X_i, X_j) = \frac{\sum_{i=1}^{n} (X_{ii} - \overline{X}_i)^2 \cdot (X_{jj} - \overline{X}_j)}{(n-1)}$$

The eigenvector with the highest eigenvalue is the first principal component C_1 for the dataset. The second highest eigenvalue is the second principal component and so on. PCA returns *n* eigenvectors and eigenvalues, as much as the initial number of variables.

Geometrically, PCA is defined as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by any projection of the data lies on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on.

Principal components analysis is commonly used for two main purposes:

- Identification of latent variables: associating a latent variable with the principal components which cannot be measured directly but only as a linear combination of the associated variables (example: intelligence, emotions, size, sustainability)

- Data reduction: selecting a certain number of variables with the highest correlation with the principle components, to be retained as the most important variables in a set.

5.5.1 Use of standardized variables

Variables standardization is a common procedure prior to performing PCA. Standardization is achieved by subtracting the mean and dividing each dataset variable by the standard deviation.

The so-called z-score for the variable X_1 is:

$$z_{1i} = \frac{X_{1i} - \bar{X}_1}{s}$$

Where s is the standard deviation of the sample X_1:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_{1i} - \bar{X}_1)^2}{(n-1)}}$$

Variables standardization is a useful practice, for the following reasons:

- PCA on standardized variables is equivalent to analyzing the correlation matrix rather than the covariance matrix.
- The total variance is simply the number of variables n, and the proportion explained is the corresponding eigenvalue divided by n.

5.5.2 Correlations between variables and components (factor loadings)

Factor loadings represent the degree of correlation of each variable with each component C_i. A Varimax rotation is commonly used to minimize the number of variables which have a high correlation with the same component C_i. The idea is to obtain a simpler structure, ideally where each indicator is loaded only on one component.

The correlation between the i^{th} principal component C_i and the j^{th} variable X_j is given by:

$$F_{ij} = \frac{a_{ij}\sqrt{(\mathrm{var}\, C_i)}}{\sqrt{(\mathrm{var}\, X_j)}}$$

Where F_{ij} is the factor loading, i.e. the correlation coefficient between the i^{th} principal component C_i and the j^{th} variable X_j, "var" is the variance and a_{ij} is the coefficient of X_j for the i^{th} principal component.

5.5.3 Number of components to be retained

The idea of PCA is to retain the number of components which accounts for as much variability as possible. Different criteria can be used, but the standard practice is to choose the principal components that: (i) have associated eigenvalues larger than one (ii) individually contribute to the explanation of overall variance by more than 10% and (iii) cumulatively account for more than 70-80% of total variance. A complementary approach is the analysis of the so-called scree plot, plotting the eigenvalues versus the component number, using the change in steepness as a cut-off point (see, for example, section 5.7.4).

5.6 Building composite indicators: weighting and aggregation

This task deals with assigning weights to the different variables to be able to aggregate them into a final composite indicator. Weighting techniques are introduced here as they will be used to assign weights to the variables of the DEDUCE database (section 5.7.5).

Weighting can be carried out using different techniques, some derived from statistical models and other derived from participatory methods (Nardo et al., 2005):

- Weighting based on statistical methods includes techniques based on principal components and factor analysis and techniques based on data envelopment analysis or unobserved components models (UCM).

- Participatory methods include budget allocation (BAL), co-joint analysis (CA) and analytical hierarchy process (AHP).

All the methods have their pros and their cons, and each of them should be chosen under special conditions.

5.6.1 Weighting based on PCA

As PCA-based weighting is used for the DEDUCE case study (section 5.7.5), this technique is explained as follows.

The approach, proposed by Nicoletti (Nicoletti et al., 2000), is based on the PCA results. In order to extract weights, the rotated factor loadings are multiplied by the proportion of the variance accounted for by each principal component.

The result is used as a measure of the importance of each variable.

Consider the following example:

PCA is applied to a system made of four variables (X_1, X_2, X_3, X_4). The results include 2 principal components, C_1 and C_2, accounting respectively for 74% and 25% of total variance (table 5.1).

Component	Total variance	% of explained Variance	Cumulative %	Proportion of explained variance P_v
1	2,968	74,199	74,199	0,74
2	1,029	25,734	99,932	0,26
Total	3,997			

Table 5.1. PCA results on a simple system comprising 4 variables.

Rotated factor loadings per variable are reported as follows (table 5.2):

Rotated components matrix		
Variable	**Component**	
	1	2
X_1	**0,97**	0,23
X_2	**0,96**	0,26
X_3	0,19	**0,98**
X_4	0,31	**0,94**

Table 5.2. Varimax rotated factor loadings of a simple system made up of 4 variables.

The highest factor loadings per variable (in bold) are retained for the next calculation. Per each variable X_i the importances W_i are then calculated by multiplying the retained factor loadings F_{iL} by the proportion of the explained variance P_{iV}:

$$W_i = F_{iL} \times P_{iV}$$

The results are reported on the following table (table 5.3).

Variable	Factor Loadings (F_L) for Component 1	Factor Loadings (F_L) for Component 2	Weights W_i
X_1	0,97		0,71
X_2	0,96		0,71
X_3		0,98	0,24
X_4		0,94	0,23
Proportion of explained variance (P_v)	0,74	0,26	

Table 5.3. Calculation of weights for data aggregation in a simple system made up of 4 variables.

5.6.2 Aggregation

Aggregation techniques are introduced here, as they will be used in section 5.7.5.

According to Nardo (Nardo et al., 2005) the most common aggregative methods are additive intermediate composite techniques. Another less widespread approach is geometric aggregation.

Additive methods

The most widespread additive aggregation is the linear summation of weighted and normalized indicators:

$$CI = \sum_{i=1}^{n} W_i I_i$$

Where *CI* is the composite indicator, W_i and I_i are respectively the weight and value of the i^{th} indicator.

Although widely used, this aggregation entails restrictions on the nature of indicators and the interpretation of the weights. A condition of the nature of indicators is that there should be no phenomena of conflict, synergy or strong correlation amongst them.

Geometric aggregation

An undesirable feature of additive aggregations is the full compensability they imply: poor performance in some indicators can be compensated by sufficiently high values of other indicators. A geometric aggregation (i.e. the product of weighted indicators) is a less compensatory approach:

$$CI = W_1 I_1 \times W_2 I_2 ... \times W_n I_n$$

5.7 Case study: Reducing data and building composite indicators to measure coastal sustainability (WG-ID indicators panel)

The EU ICZM Expert Group established a Working Group on Indicators and Data (WG-ID) in 2002 to advise it on ways in which Member States and the EU as a whole can assess whether they are moving towards or away from a more sustainable future for their coastal zones, and at what pace. The WG-ID drew up a set of indicators of sustainable coastal zone development (SD indicators).

The system model, designed to describe the state and progress of the coastal zone towards sustainability, has been drawn up by experts who identified 7 goals, 27 indicators and 44 measurements including (at least) 61 variables.

The validity of this theoretical framework is supported by an interdisciplinary team of experts, who designed a comprehensive model for the measurement of coastal zone sustainability. Despite this, the model is not easily understandable by non-expert end-users nor is it easily manageable by policy makers.

In 2004, nine partners representing all decision-making levels (European, national, regional and local) created the DEDUCE project, under the Interreg3c funding scheme, with the aim of calculating and standardizing procedures, to collect data and calculate the coastal sustainability indicators (SD Indicators) at different pilot sites along the project partners' coasts (Catalonia, France, West Flanders, Poland, Malta and Latvia). The results of the project include two main products:

1. The Standard Indicator Format - SIF: defines and describes the methodology of calculation.
2. The Indicator Fact Sheet – IFS: summarizes and communicates the main information obtained by partners on each indicator.

The DEDUCE partners recognized the need to develop an integrated analysis of the calculation of the results to describe the types of relationships and to uncover cause-effect relationships. The key elements of this analysis should be the following:

1. Defining cause-effect relationships.
2. Establishing agreed thresholds and targets.
3. Weighting the relative value of the indicators.

In the framework of this thesis, a fully statistical approach has been chosen to explore multivariate statistics using the DEDUCE datasets, to improve understanding of the system structure (correlations and possible causalities), to reduce the number of variables and to propose a set of composite indicators which can represent trends in the level of coastal sustainability.

The analysis has been carried out on datasets published by the Generalitat de Catalunya (Generalitat de Catalunya, 2008), which reports the evolution of the 27 indicators in coastal municipalities in the period 1980-2006.

The approach is based on the following steps: (i) critical revision of the system model (ii) data collection (iii) imputation of missing values (iv) principal component analysis.

5.7.1 Revision of the system model

The WG-ID used a goal-oriented approach to identify the evolution of the coastal system. Each goal was subsequently disaggregated into indicators, measurements and variables (see table 5.4). The corresponding variables are reported in table 5.6.

Goals	Indicators	Measurements
1. To control further development of the undeveloped coast as appropriate	1. Demand for property on the coast	1.1 Size, density and proportion of population living on the coast
		1.2 Value of residential property
	2. Area of built-up land	2.1 Percentage of built-up land by distance from the coastline
	3. Rate of development of previously undeveloped land	3.1 Area converted from non developed to developed land uses
	4. Demand for road travel on the coast	4.1 Volume of traffic on coastal motorways and major roads
	5. Pressure for coastal and marine recreation	5.1 Number of moorings for recreational boating
	6. Land taken up by intensive agriculture	6.1 Proportion of agriculture land farmed intensively
2. To protect, enhance and celebrate natural and cultural diversity	7. Amount of semi-natural habitat	7.1 Area of semi-natural habitat
	8. Area of land and sea protected by statutory designations	8.1 Area protected for nature conservation, landscape and heritage
	9. Effective management of designated sites	9.1 Rate of loss or damage to protected areas
	10. Change in significant coastal and marine habitat and species	10.1 Status and trend of specified habitats and species
		10.2 Number of species per habitat type
		10.3 Number of red-list coastal area species
3. To promote and support a dynamic and sustainable coastal economy	11. Loss of cultural distinctiveness	11.1 Number and value of sales of local products with regional quality labels
	12. Sector employment patterns	12.1 Full time, part time and seasonal employment per sector
		12.2 Added-value per sector
	13. Volume of port traffic	13.1 Number of incoming and outgoing passengers per port
		13.2 Total volume of goods handled per port

		13.3. Proportion of goods carried by short sea routes
	14. Intensity of tourism	14.1 Number of overnight stays in tourist accommodation
		14.2. Bed occupancy rate
	15. Sustainable tourism	15.1 Number of tourist accommodation units holding EU Eco-label
		15.2 Ratio of overnight stays to number of residents
4. To ensure that beaches are clean and coastal waters unpolluted	16. Quality of bathing waters	16.1 Percentage of bathing waters compliant with the European Bathing Water Directive value guide
	17. Amount of coastal, estuarine and marine litter	17.1 Volume of litter collected per given length of shoreline
	18. Concentration of nutrients in coastal waters	18.1. Riverine and direct nitrogen and phosphorus inputs in inshore waters
	19. Amount of oil pollution	19.1. Volume of accidental oil spills
		19.2. Number of observed oil slicks from aerial surveillance
5. To reduce social exclusion and promote social cohesion in coastal areas	20.Degree of social cohesion	20.1. Indices of social exclusion by area
	21. Relative household prosperity	21.1. Average household income
		21.2. Percentage of population with a higher education qualification
	22. Second and holiday homes	22.1. Ratio of first to second and holiday homes
6. To use natural resources wisely	23. Fish stocks and fish landings	23.1. State of the main fish stocks by species and sea area
		23.2. Landings and fish mortality by species
		23.3. Value of landings by port and species
	24. Water consumption	24.1. Number of days of reduced supply
7. To recognize the threat to coastal zones posed by climate change and to ensure appropriate and ecologically responsible coastal protection.	25. Sea level rise and extreme weather conditions	25.1 Number of stormy days
		25.2. Rise in sea level relative to land
		25.3. Length of protected and defended coastline
	26. Coastal erosion and accretion	26.1. Length of dynamic coastline
		26.2. Area and volume of sand nourishment
	27. Natural and human economic assets at risk	27.2. Number of people living within an 'at risk' zone
		27.2. Area of protected sites within an 'at risk' zone
		27.3. Value of economic assets within an 'at risk' zone

Table 5.4. The theoretical framework which defines “coastal sustainability” designed the WG-ID.

Per goal, the number of indicators and measurements is not constant. In the next table (table 5.5) we can see that the number of goals, indicators and measurements is not evenly distributed, with a total number of 7 goals, 27 indicators and 44 measurements. This situation becomes even more complex as each measurement, as we will see in the next part on data collection, can be done using a different number of variables.

Goals	Short name	Number of indicators	Number of measurements
1. To control further development of the undeveloped coast as appropriate	PRESSURE	6	7
2. To protect, enhance and celebrate natural and cultural diversity	DIVERSITY	4	6
3. To promote and support a dynamic and sustainable coastal economy.	ECONOMY	5	10
4. To ensure that beaches are clean and coastal waters unpolluted	POLLUTION	4	5
5. To reduce social exclusion and promote social cohesion in coastal areas	SOCIETY	3	4
6. To use natural resources wisely	RESOURCES	2	4
7. To recognize the threat to coastal zones posed by climate change and to ensure appropriate and ecologically responsible coastal protection.	PHYSICS	3	8
TOTAL	7	27	44

Table 5.5. Summary of the structure of the theoretical framework of the WG-ID.

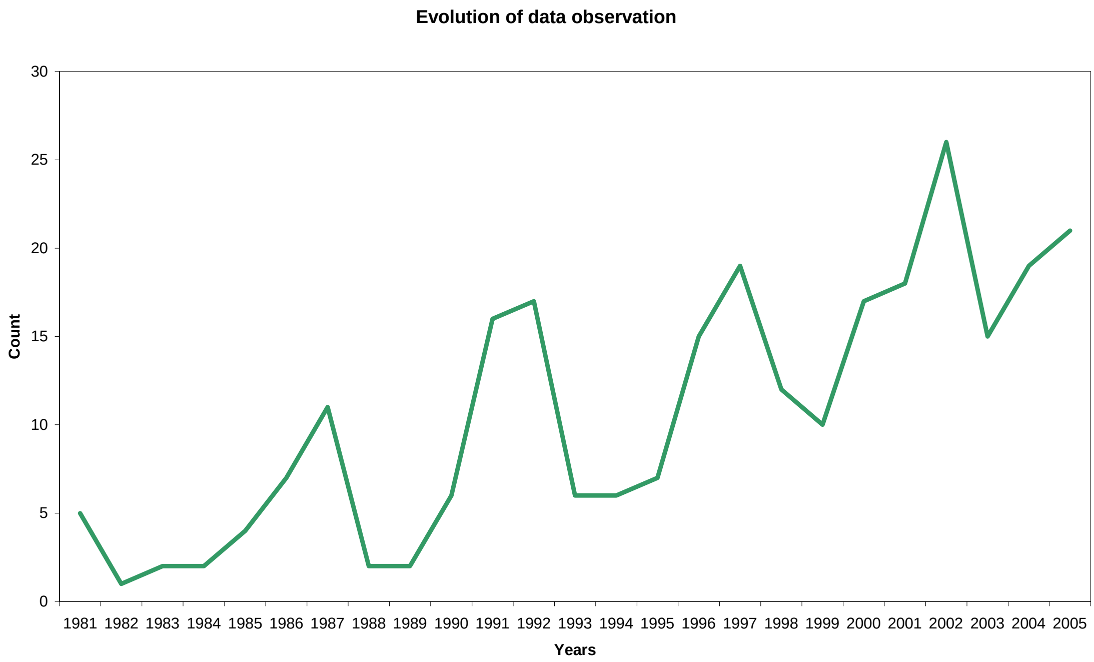
The next sections will show how the redundancy of this scheme can be analyzed using multivariate statistics techniques such as principal components analysis (PCA), ultimately to reduce the number of variables to be measured and improve the cost-effectiveness of data collection (section 5.7.6). At the same time, PCA will bring in information about the weights (importance) of each variable in terms of the variance of each dataset (section 5.7.5).

5.7.2 Data collection

In the framework of the DEDUCE Project, data were collected at different pilot sites along project partners' coasts. In this study we have analyzed the available data from the DEDUCE datasets collected for the Catalunya Region (Generalitat de Catalunya, 2006).

Data were available for download in xls format. Each measurement often included more than one variable and data had significant gaps along the time series, where each variable represented the average value measured in coastal municipalities of the Catalunya region between 1980 and 2005.

Gaps probably depended on time resolution of data collection and on data availability in specific years. Graph 5.1 reports the distribution of data over time. We can observe an increase in data availability and different peaks which correspond to variables collected regularly, every three to five years.



Graph 5.1. Evolution of DEDUCE database, data availability 1980- 2006 .

The following table (table 5.6) provides information regarding the number of variables corresponding to each measurement, their units of measurement, and data availability constraints. The nature, quality, temporal distribution and availability of the data are used as criteria for their inclusion in the subsequent analysis: of 61 variables reported in the DEDUCE database, only 49 datasets were available in the xls sheets.

Out of these, only 27 could be used for missing value imputation, as this imputation is only possible if some regularity or trend exists in the variables observed: few variables did not meet this condition and were excluded from further analysis. These are (i) variables with less than 4 observations and/or observations covering really short periods (3 to 5 years) or (ii) variables with random values. In both cases, missing value imputation could lead to misleading results.

Measurements	Variable	Units of measurement	Count	Inclusion (Y/N)
1.1 Size, density and proportion of the population living on the coast	Population	n	6	Y
	Percentage of the total Catalunya population	%	6	Y
	Density	hab/km^2	6	Y
1.2 Value of residential property	New property prices	€/m^2	8	Y
	Price of 2nd hand properties	€/m^2	8	Y
2.1 Percentage of built-up land by distance from the coastline	Area of built up land in 0-1 km	%	4	Y
	Area of built up land in 0-10 km	%	4	Y
	Area of built up land in coastal municipalities	%	4	Y
3.1 Area converted from non developed to developed land uses	Unbuilt land in coastal municipalities	%	4	N
	Yearly increase of built-up land	%	3	N
4.1 Volume of traffic on coastal motorways and major roads	Number of transits on coastal highways	n	8	Y
	Average number of daily transits on coastal roads	n	5	Y
5.1 Number of moorings for recreational boating	Number of moorings	n	6	Y
6.1 Proportion of agriculture land farmed intensively	Area of agricultural land	Ha	4	Y
	Area of intensive agriculture land	Ha	4	Y
7.1 Area of semi-natural habitat	Area of natural or semi-natural habitats in coastal municipalities	%	4	Y
	Area of natural or semi-natural habitats in 0-1 km	%	4	Y
	Area of natural or semi-natural habitats in 0-10 km	%	4	Y
8.1 Area protected for nature conservation, landscape and heritage	Area of MPAs in coastal waters (depth < 100 m)	%	1	N
	Protected areas in 0-10 km	%	1	N
9.1 Rate of loss or damage to protected areas	N/A	N/A	0	N
10.1 Status and trend of specified habitats and species	N/A	N/A	0	N
10.2 Number of species per habitat type	N/A	N/A	0	N
10.3 Number of red-list coastal area species	Number of marine species	n	5	N
	Number of marine species on the IUCN red list	n	5	N
	Marine species on the IUCN red list	%	5	N
11.1 Number and value of sales of local products with regional quality labels or European PDO/PGI/TSG	Local products in the coastal zone	%	1	N

12.1 Full time, part time and seasonal employment per sector	Employment rate in coastal municipalities	%	4	Y
12.2 Added value per sector	N/A	N/A	0	N
13.1 Number of incoming and outgoing passengers per port	N/A	N/A	0	N
13.2 Total volume of goods handled per port	N/A	N/A	0	N
13.3. Proportion of goods carried on short sea routes	Goods carried on short sea routes	%	8	N
14.1 Number of overnight stays in tourist accommodation	N/A	N/A	0	N
14.2. Bed occupancy rates	N/A	N/A	0	N
15.1 Number of tourist accommodation units holding EU Eco-label	N/A	N/A	0	N
15.2 Ratio of overnight stays to number of residents	N/A	N/A	0	N
16.1 Percentage of bathing waters compliant with the European Bathing Water Directive value guide	Percentage of bathing waters compliant with the European Bathing Water Directive value guide	%	15	Y
17.1 Volume of litter collected per given length of shoreline	Volume of litter collected	m^3/km	4	N
18.1. Riverine and direct nitrogen and phosphorus inputs inshore waters	Nitrates	µmol/l	5	Y
	Phosphates	µmol/l	5	Y
19.1. Volume of accidental oil spills	Oil collected in coastal waters	m^3	4	N
	Oil collected in coastal waters	l	4	N
19.2. Number of observed oil slicks from aerial surveillance	Number of observed oil slicks from aerial surveillance	n	6	N
20.1. Indices of social exclusion by area	N/A		0	N
21.1. Average household income	Average household income in coastal municipalities	€	3	Y
	Average per-capita income in coastal municipalities	€	3	Y
21.2. Percentage of population with a higher education qualification	Population with a higher education qualification	n	5	Y
22.1. Ratio of first to second and holiday homes	Ratio of first to second and holiday homes	%	3	Y
23.1. State of the main fish stocks by species and sea area	Percentage of species under the overfishing limit	%	5	N
23.2. Landings and fish mortality by species	Total landings	t	16	Y
23.3. Value of landings by port and species	Total value of landings	€	9	N
24.1. Number of days of reduced supply	Number of days of reduced supply	n	2	N
25.1 Number of stormy days	Number of days with waves higher than 2 m for 6 h	n	11	Y

25.2. Rise in sea level relative to land	Relative sea level rise	mm	14	Y
25.3. Length of protected and defended coastline	Coastal infrastructure length	%	1	N
26.1. Length of dynamic coastline	Coast in erosion	%	1	N
26.2. Area and volume of sand nourishment	Volume of sand	m^3*1000	16	N
	Length of nourishment	m	16	N
27.2. Number of people living within an 'at risk' zone	Percentage of population living in risk zone of coastal or river floods in coastal municipalities	%	1	N
27.2. Area of protected sites within an 'at risk' zone	Percentage of the area of protected areas under risk of river or marine flood in coastal municipalities	%	1	N
27.3. Value of economic assets within an 'at risk' zone	N/A	N/A	0	N
TOTAL	61	49		27

Table 5.6. Available variables representing each of the measurements based on the WG-ID framework. The "Count" column represents the number of observations available.

The complete matrix, based on the available datasets, is reported in Annex I.

5.7.3 Imputation of missing values

The DEDUCE dataset is a 25-year time series of the variables making up the WG-ID indicator panel, calculated as averages for the whole coastal zone of Catalunya.

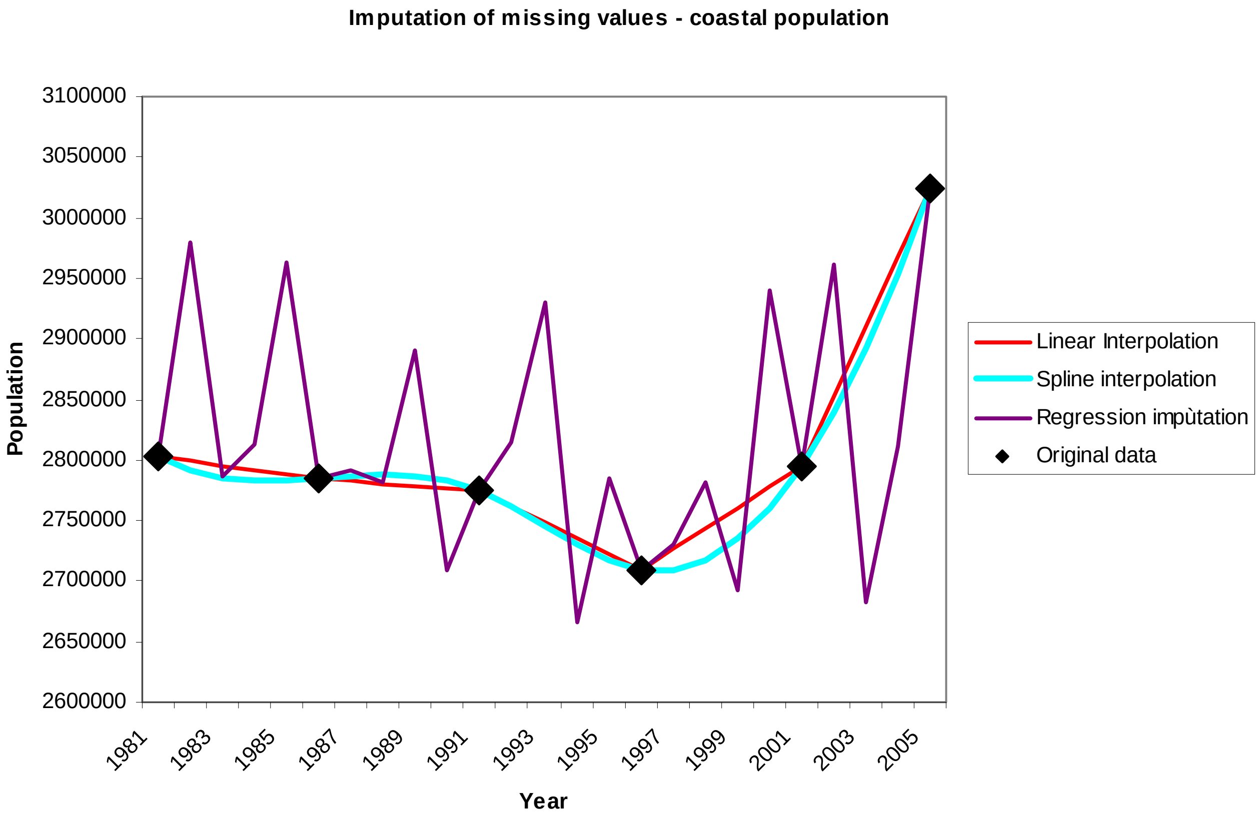
With the DEDUCE case study, the objective of the imputation of missing values was to build a matrix 25 x 27 where 25 is the number of observations, 1 per year, and 27 is the number of selected variables.

Three imputation techniques were tested:

1. Simple regression imputation
2. Linear interpolation
3. Spline interpolation imputation

As explained in section 5.4, (i) in a simple regression imputation, missing values are substituted by the predicted values obtained from regression, (ii) in a linear interpolation, blanks are filled in by the values obtained from a linear interpolation between the existing values and (iii) in a spline interpolation blanks are filled in by the values obtained from a cubic spline function, resulting in a smoother interpolation.

The performance of the three techniques in the imputation of one specific indicator is reported in the following graph (graph 5.2).



Graph 5.2. Performance of three different, imputations of missing value techniques applied to the "coastal population" variable.

The best performance in this case is given by the spline and linear interpolations. Regression imputation has a low performance, as no regressor (independent variable) shows that a strong relationship with the dependent variable is available.

The 25 x 27 matrix resulting from spline interpolation was finally used to perform PCA.

The matrices before and after imputation are reported in Annex I.

5.7.4 Principal component analysis

As explained in section 5.5, Principal Component Analysis (PCA) is a multivariate statistical technique which can be used to understand the structure of data and to identify the underlying factors (principal components) which account for as much variance as possible.

PCA leads to an important reduction in terms of variables to be measured, as much of the variance accounts for a limited number of independent variables.

In the case of the DEDUCE database, PCA was performed for each goal making up the system. PCA on the whole set of variables was not performed as the DEDUCE theoretical framework identifies coastal sustainability in 7 separated and equal-weighted goals.

Goal 1: To control further development of the undeveloped coast as appropriate

13 variables were available for Goal 1, reported on the following table (table 5.7).

Code	Name	Short name
1.1.1	Population	COASTPOP
1.1.2	Percentage of the total Catalunya population	PERCCOASTPOP
1.1.3	Density	DENSITY
1.2.1	New property prices	PRICEHOUSES
1.2.2	2nd hand property prices	PRICE2NDHOUSES
2.1.1	Area of built up land in 0-1 km	BUILTUPLAND1KM
2.1.2	Area of built up land in 0-10 km	BUILTUPLAND10KM
2.1.3	Area of built up land in coastal municipalities	BUILTUPLANDCM
4.1.1	Number of transits in coastal highways	HIGHWAYSTRANSITS
4.1.2	Average number of daily transits in coastal roads	ROADSTRANSITS
5.1.1	Number of moorings	MOORINGS
6.1.1	Extension of agriculture land	AGRILAND
6.1.2	Extension of intensive agriculture land	INTENSEAGRILAND

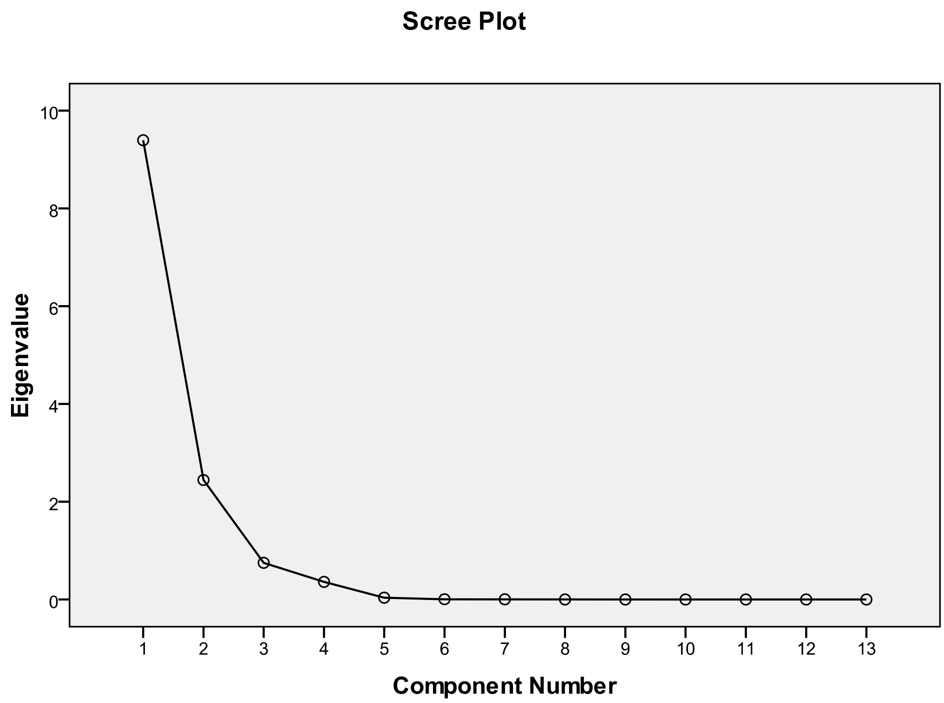
Table 5.7. Variables belonging to Goal 1 used for PCA.

The results of the PCA show that the first two components account for as much variance as possible (table 5.8).

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	9,395	72,266	72,266
2	2,444	18,803	91,069
3	,751	5,780	96,850
4	,361	2,773	99,623
5	,038	,292	99,915
6	,006	,043	99,958
7	,004	,027	99,985
8	,001	,010	99,995
9	,000	,004	99,999
10	,000	,001	100,000
11	2,625E-5	,000	100,000
12	2,030E-8	1,562E-7	100,000
13	3,834E-17	2,949E-16	100,000

Table 5.8. PCA results for Goal 1.

The scree plot confirms the factor to be retained: after variable 2, a change in slope can be detected (graph 5.3).



Graph 5.3. Scree plot, Goal 1 PCA.

A Varimax rotation of the correlation matrix between variables and components was used to identify the variables to be retained: ROADTRANSIT, BUILTUPLAND1KM, MOORINGS, COASTPOP (variables values in bold). The variables COASTPOP and DENSITY have the same correlation coefficient with the component, as the latter is derived from the first one. Only COASTPOP was therefore retained (table 5.9).

Rotated Component Matrix[a]		
	Component	
	1	2
Zscore: LINT(ROADSTRANSITS)	**,980**	,149
Zscore: LINT(BUILTUPLAND1KM)	**,964**	,236
Zscore: LINT(MOORINGS)	**,955**	,279
Zscore: LINT(INTENSEAGRILAND)	-,910	-,396

Zscore: LINT(PERCCOASTPOP)	-,909	-,387
Zscore: LINT(HIGHWAYSTRANSITS)	,840	,518
Zscore: LINT(BUILTUPLAND10KM)	-,809	,339
Zscore: LINT(AGRILAND)	-,760	-,338
Zscore: LINT(COASTPOP)	,088	**,932**
Zscore: LINT(DENSITY)	,088	,932
Zscore: LINT(BUILTUPLANDCM)	,283	,822
Zscore: LINT(PRICEHOUSES)	,654	,745
Zscore: LINT(PRICE2NDHOUSES)	,684	,725
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.		
a. Rotation converged in 3 iterations.		

Table 5.9. Factor loadings between variables and components, Goal 1.

Goal 2: To protect, enhance and celebrate natural and cultural diversity

Three variables were available for Goal 2, reported in the following table (table 5.10).

CODE	NAME	SHORT NAME
7.1.1	Area of natural or semi-natural habitats in coastal municipalities	NATINCM
7.1.2	Area of natural or semi-natural habitats in 0-1 km	NATIN1
7.1.3	Area of natural or semi-natural habitats in 0-10 km	NATIN10

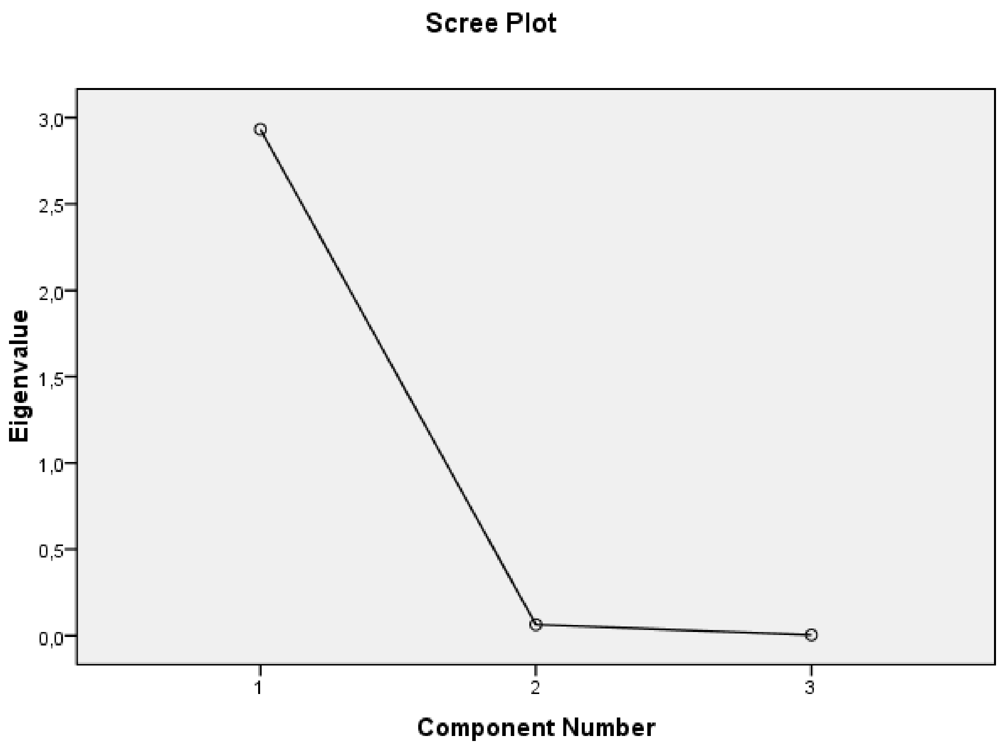
Table 5.10. Variables belonging to Goal 2 used for PCA.

The results show that most of the variance is accounted for by the first component (table 5.11).

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2,932	97,749	97,749	2,932	97,749	97,749
2	,064	2,122	99,871			
3	,004	,129	100,000			
Extraction Method: Principal Component Analysis.						

Table 5.11. PCA results for Goal 2.

The scree plot is reported as follows (graph 5.4).



Graph 5.4. Scree plot, Goal 2 PCA.

As only one component could be extracted, no varimax rotation was performed. NATIN1 accounts for the maximum variance of the three variables (table 5.12).

Component Matrix	
	Component
	1
Zscore: LINT(NATINCM)	,989
Zscore: LINT(NATIN10)	,980
Zscore: LINT(NATIN1)	,998
Extraction Method: Principal Component Analysis.	
a. 1 component extracted.	

Table 5.12. Factor loadings between variables and components, Goal 2.

Goal 3. To promote and support a dynamic and sustainable coastal economy

Only one variable among the available datasets was imputed for missing value. In this case, no PCA can be performed. The EMPLOYMENT variable was therefore considered the best available information for Goal 3 (table 5.13).

CODE	NAME	SHORT NAME
12.1.1	Employment rate in coastal municipalities	EMPLOYMENT

Table 5.13. Variables belonging to Goal 3.

Goal 4. To ensure that beaches are clean and coastal waters unpolluted

Three variables were available for Goal 4, reported on the following table (table 5.14).

CODE	NAME	SHORT NAME
16.1.1	Percentage of bathing waters compliant with the European Bathing Water Directive value guide	QUALBATHWATER
18.1.1	Nitrates	NITRATES
18.1.2	Phosphates	PHOSPHATES

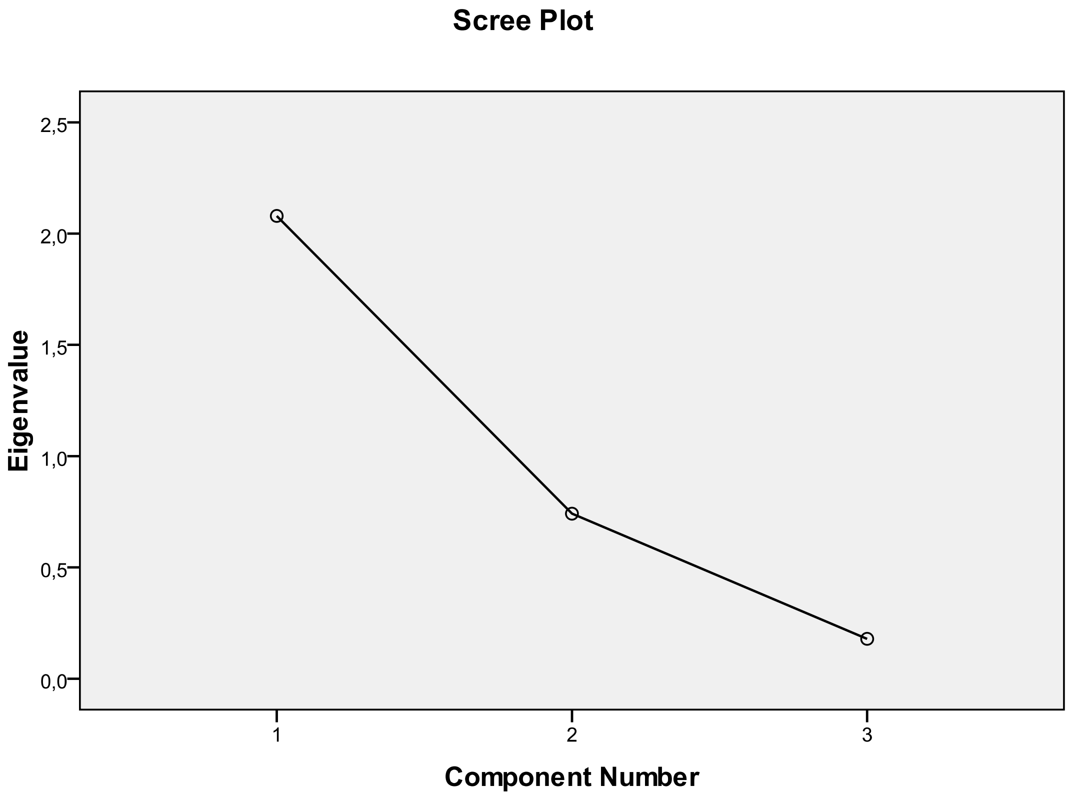
Table 5.14. Variables belonging to Goal 4 used for PCA.

The results show that most of the variance is accounted for by the first component (table 5.15).

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2,079	69,308	69,308	2,079	69,308	69,308
2	,742	24,726	94,034			
3	,179	5,966	100,000			
Extraction Method: Principal Component Analysis.						

Table 5.15. PCA results for Goal 4.

The scree plot is reported as follows (graph 5.5).



Graph 5.5. Scree plot, Goal 4 PCA.

As only one component could be extracted, no varimax rotation was performed. PHOSPHATES accounts for the maximum variance of the three variables (table 5.16).

Component Matrix[a]	
	Component
	1
Zscore: LINT(PHOSPHATES)	,938
Zscore: LINT(QUALBATHWATER)	,874
Zscore: LINT(NITRATES)	,660
Extraction Method: Principal Component Analysis.	
a. 1 components extracted.	

Table 5.16. Factor loadings between variables and components, Goal 4.

Goal 5: To reduce social exclusion and promote social cohesion in coastal areas

Four variables were available for Goal 5, reported on the following table (table 5.17).

CODE	NAME	SHORT NAME
21.1.1	Average household income in coastal municipalities	INCOMECM
21.1.2	Average income per-capita in coastal municipalities	INCOMEPCCM
21.2.1	Population with a higher education qualification	HIGHEDU
22.1.1	Ratio of first to second and holiday homes	FIRST2NDHOUSE

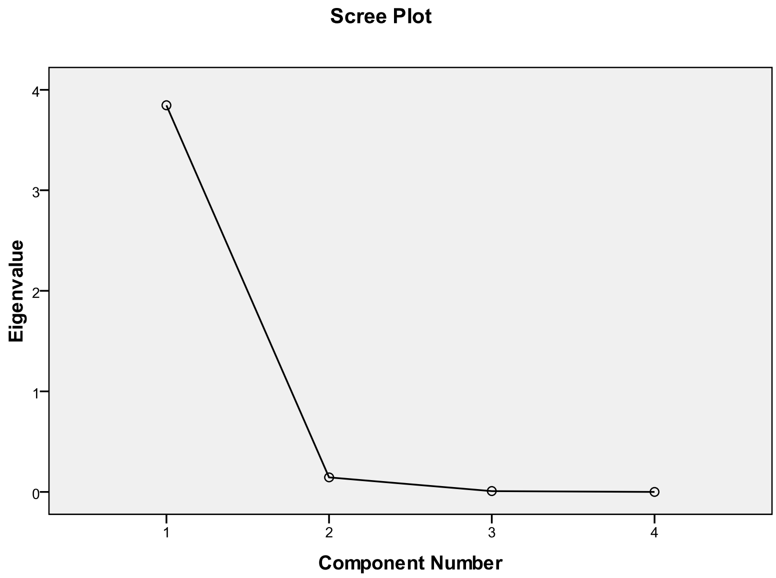
Table 5.17. Variables belonging to Goal 5 used for PCA.

The results show that most of the variance is accounted for by the first component (table 5.18).

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3,846	96,147	96,147	3,846	96,147	96,147
2	,145	3,619	99,766			
3	,009	,220	99,986			
4	,001	,014	100,000			
Extraction Method: Principal Component Analysis.						

Table 5.18. PCA results for Goal 5.

The scree plot confirms the factor to be retained: after variable 2 a change in slope can be detected (graph 5.6).



Graph 5.6. Scree plot, Goal 5 PCA.

As only one component could be extracted, no varimax rotation was performed. Two variables should be retained: INCOMECM and HIGHEDU. INCOMEPCCM is a derived variable of INCOMECM with a slightly lower correlation with component 1, and is not retained (table 5.19).

Component Matrix[a]

	Component
	1
Zscore: LINT(INCOMECM)	,994
Zscore: LINT(HIGHEDU)	,993
Zscore: LINT(INCOMEPCCM)	,991
Zscore: LINT(FIRST2NDHOUSE)	,943

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Table 5.19. Factor loadings between variables and components, Goal 5.

Goal 6: To use natural resources wisely

Only one variable was available. In this case, no PCA can be performed. The variable LANDINGFISH is therefore considered as the best information available for Goal 6 (table 5.20).

CODE	NAME	SHORT NAME
23.2.1	Total fish landings	LANDINGFISH

Table 5.20. Variables belonging to Goal 6.

Goal 7: To recognize the threat to coastal zones posed by climate change and ensure appropriate and ecologically responsible coastal protection.

Two variables are available for Goal 7 (table 5.21).

CODE	NAME	SHORT NAME
25.1.1	Number of days with waves higher than 2 m for 6 h	WAVES
25.2.1	Relative sea level rise	SEALEVEL

Table 5.21. Variables belonging to Goal 7 used for PCA.

PCA shows the existence of two principal components accounting for a similar value of variance in the datasets, meaning that no correlation was detected between them: both variables are therefore retained (table 5.22).

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1,046	52,284	52,284	1,046	52,284	52,284
2	,954	47,716	100,000			
Extraction Method: Principal Component Analysis.						

Table 5.22. PCA results for Goal 7.

5.7.5 Weighting and aggregation

PCA results provide values for weighting. Using the methodology proposed by Nardo (Nardo et al., 2005), a composite indicator for each goal can be built by grouping variables in intermediate composite indicators. The intermediate indicators are then aggregated by weighting each composite using the proportion of the explained variance in the dataset.

This whole procedure is carried out completely for Goal 1 only as the other variables have either equal rotated factor loadings or equal proportions of the variance explained. The following table reports the values needed for the calculation of each composite indicator (table 5.23).

Goal short name	Variable	Component	Explained variance (%)	Factor loading (F_L)	Explained variance per factor	Proportion of explained variance (P_V)
PRESSURE	ROADTRANSITS	1	72,266	0,98	9,40	0,79
	BUILTUPLAND1KM			0,96	9,40	0,79
	MOORINGS			0,95	9,40	0,79
	COASTPOP	2	18,803	0,93	2,44	0,21
DIVERSITY	NATIN1	1	96,47	N/A	1	1
ECONOMY	EMPLOYMENT	N/A	N/A	N/A	N/A	N/A
POLLUTION	BATHING WATER	1	69,308	0,95	2,07	0,74
	NITRATES	2	24,726	0,97	0,74	0,26
SOCIETY	INCOME	1	96,147	0,85	1	1
	HIGHEDU			0,84	1	1
RESOURCES	LANDINGFISH	N/A	N/A	N/A	N/A	N/A
PHYSICS	WAVES	1	52,348	1	1,047	0,52
	SEA LEVEL	2	47,652	1	0,953	0,48

Table 5.23. Factor loadings and proportion of explained variance for the selected variables.

The resulting composite indicators for each goal are therefore calculated using the procedure explained in section 5.6.1:

$$W_i = F_{Li} \times P_{Vi}$$

Where W_i, F_{Li} and P_{Vi} are respectively weight, factor loading and proportion of explained variance for the i^{th} variable, the following table reports the indicators and the composite indicators for each goal (table 5.24).

Goal's short name	Variable	(Composite) indicators per goal
PRESSURE	ROADTRANSITS	0,79*(0,98*ROADTRANSIT+0,96*BUILTUPLAND1KM+0,95*MOORINGS)+0,21COASTPOP
	BUILTUPLAND1KM	
	MOORINGS	
	COASTPOP	
DIVERSITY	NATIN1	NATIN1
ECONOMY	EMPLOYMENT	EMPLOYMENT
POLLUTION	BATHWATER	0,95*BATHWATERS+0,97*NITRATES
	NITRATES	
SOCIETY	INCOME	0,85*INCOME+0,84*HIGHEDU
	HIGHEDU	
RESOURCES	LANDINGFISH	LANDINGFISH
PHYSICS	WAVES	0,52*WAVES+0,48*SEALEVEL
	SEALEVEL	

Table 5.24. Indicators and composite indicators per goal.

Aggregation of the different goals could be performed using a common equal weighting approach, following the assumptions of the WG-ID (each goal equally-weighted).

5.7.6 Results

The DEDUCE database analysis led to a substantial data reduction (table 5.25).

Limitations in data availability were partly overcome using missing value imputation techniques and imputation of values using expert knowledge, but many variables were excluded from the beginning of the analysis as they were not available for this research. Of the 61 initial variables considered by the DEDUCE database, 27 were actually used for data reduction using multivariate statistics.

The final number of variables retained was 11, 18% of the initial variables.

Considering only the variables analyzed, the effective data reduction based on PCA was 56%.

The detailed results for the whole set of goals and variables are summarized on the following table where the reduction percentage is reported per goal.

Goal	Initial number of variables	Available datasets	Filtering based on expert knowledge	Variables used in PCA	Final variables	Reduction based on PCA
1. To control further development of the undeveloped coast as appropriate	15	15	13	13	4	69 %
2. To protect, enhance and celebrate natural and cultural diversity	11	8	3	3	1	67 %
3 To promote and support a dynamic and sustainable coastal economy	10	3	1	N/A	N/A	N/A
4 To ensure that beaches are clean and coastal waters unpolluted	7	7	3	3	2	33 %
5. To reduce social exclusion and promote social cohesion in coastal areas	5	4	4	4	2	50 %
6. To use natural resources wisely	4	4	1	N/A	N/A	N/A
7. To recognize the threat to coastal zones posed by climate change and to ensure appropriate and ecologically responsible coastal protection.	9	8	2	2	2	0 %
TOTAL	61	49	27	25	11	56%

Table 5.25. Results of data reduction for the DEDUCE database.

5.8 Case study: reducing data of the Cantabria Oil Spill Vulnerability Atlas (COSVA)

The objective of the exercise is to explore the datasets used to prepare the Cantabria Oil Spill Vulnerability Atlas (COSVA) in order to identify the variables which account for the largest possible amount of information. Because many variables are used to calculate the proposed vulnerability index, a reduction in their number can ease maintenance of databases used by coastal managers responsible for updating them, reducing data collection costs.

The approach is based on the following steps: (i) critical revision of the system model (ii) data collection (iii) principal components analysis.

5.8.1 Revision of the system model

The theoretical framework (the system model) described by the COSVA has three components (Fernández et al., 2007):

- Socio-economic component.
- Physical component.
- Ecological component.

Each component includes different variables, used to calculate a final index. The assessment units were determined by splitting the entire coastline into 200 m sections, resulting in 1237 cases.

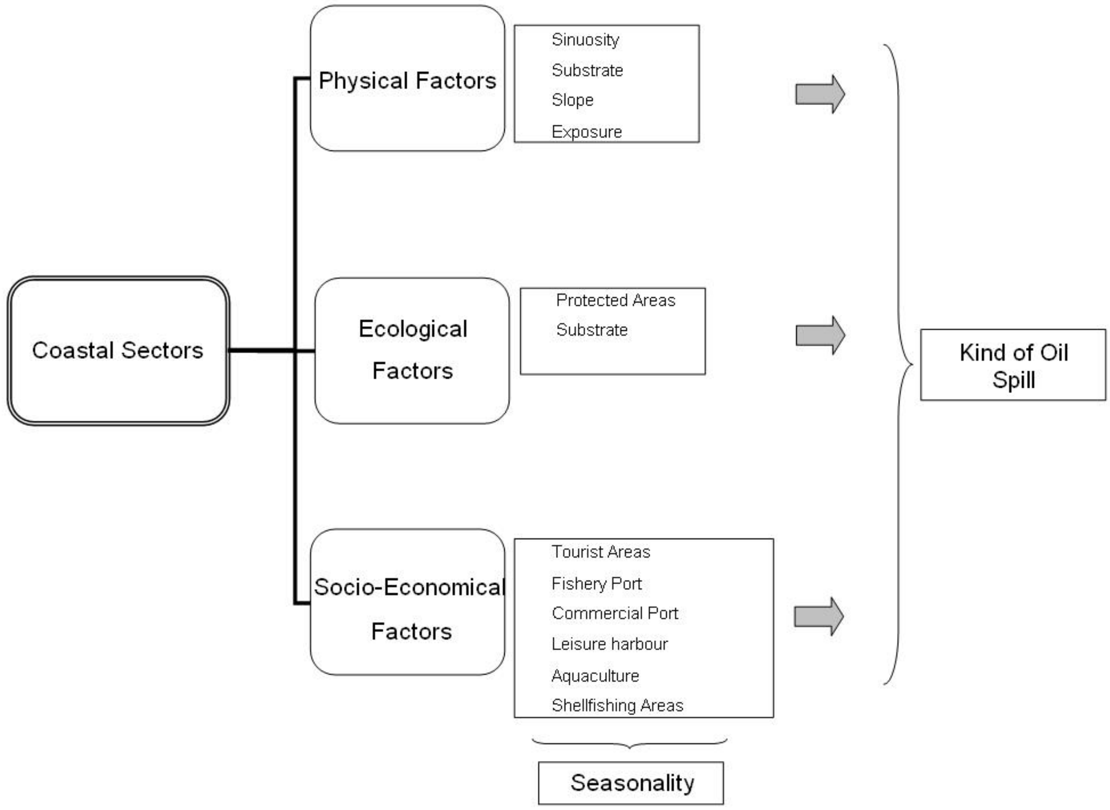


Figure 5.1.The COSVA theoretical framework, resulting in a relational data model (Fernández et al., 2007).

Socio-economic sub-system

The following are the variables included in the Socio-economic Index ($€_{tot}$), expressed in terms of monetary losses in case of oil spill:

$$€t = €_{TA} + €_{FP} + €_{CP} + €_{LH} + €_{A} + €_{SA} + €_{C}$$

where $€_{TA}$ are the losses on Tourism activities, $€_{FP}$ losses on Fisheries activity, $€_{CP}$ losses on Commercial activities, $€_{LH}$ losses on Leisure activities, $€_{A}$ losses on Aquaculture activity, $€_{SA}$ losses on Shell fishing activity and $€_{C}$ is the Cleaning cost.

Each of these activities is calculated taking into account the kind of fuel and the seasonality. The percentage affected and recovery time vary depending on the kind of fuel. The Socio-economic Index, €t, is the sum of the losses per activity, integrating the different variables.

Physical sub-systerm

Oceanographic aspects such as sea level and swell action have to be taken into account to understand and evaluate the coast's possible self-cleaning capacity. Two parameters were used to obtain the Physical Index: exposure (E) and the coast slope (S):

$PI = E + S$

Ecological sub-system

Three indexes were proposed to calculate the Ecological index. The Conservation Index (I_c) evaluates the structure, nature and extension of the environment sampled, the Singularity Index (I_s) evaluates the exclusivity and singularity of the environment sampled and the Affection Index (I_a) evaluates the environment's likelihood to be affected and its ability to recover.

The following equation calculates the Ecological Index, combining each of the indices previously calculated:

$EI = I_c + I_s + I_a$

5.8.2 Data collection

The COSVA database atlas was complete, and no MVA was required to fill gaps. Data were available in xls format.

5.8.3 Principal components analysis

PCA was carried out to identify which of the 14 variables (table 5.26) account for the highest amount possible of information in terms of variance.

Sub-system	Variable
Socio-economic	FISHERIES
	PORT
	AQUACULTURE
	TOURISM
	SHELLFISH
	RECREATION
	MARINA
	CLEANING
Physical	SLOPE
	EXPOSURE
	SINUOSITY
Ecological	AFFECTION
	CONSERVATION
	SINGULARITY

Table 5.26. Variables included in the COSVA Database.

The idea is to reduce the number of datasets to a more manageable level, reducing the number of variables and therefore the costs of updates.

Socio-economic sub-system

PCA was run on the eight socio-economic sub-system variables. The following tables report the result of the calculation.

While 4 or 5 principal components could be extracted, there is no clear evidence of the existence of one or two components accounting for the largest possible amount of the sub-system variance (table 5.27).

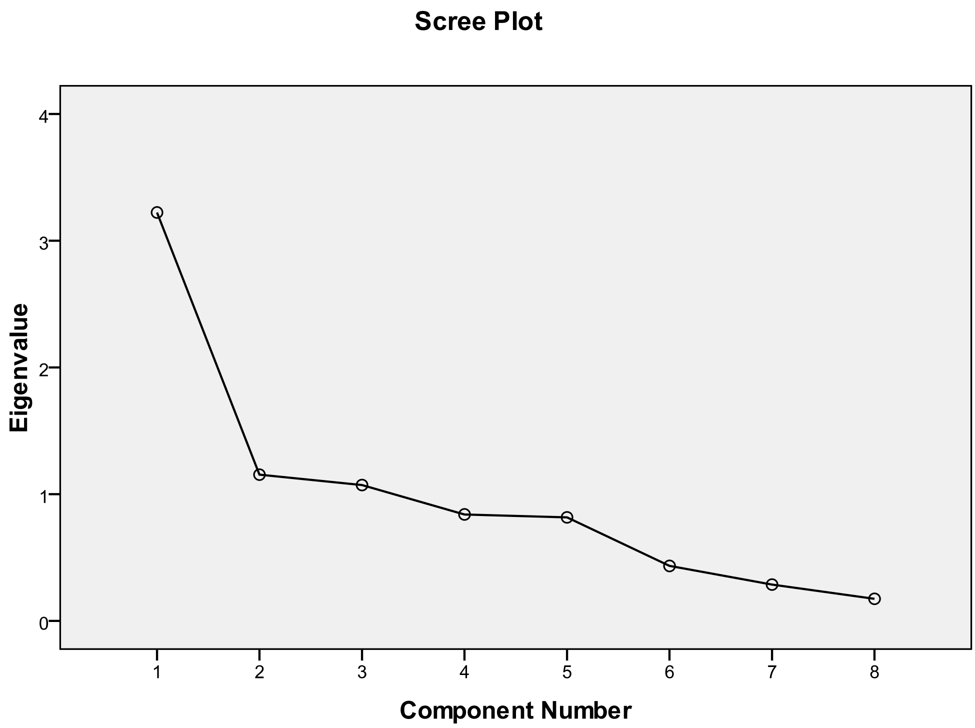
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3,223	40,288	40,288	3,223	40,288	40,288
2	1,154	14,422	54,710	1,154	14,422	54,710
3	1,072	13,396	68,106	1,072	13,396	68,106
4	,840	10,500	78,606	,840	10,500	78,606
5	,817	10,212	88,818	,817	10,212	88,818
6	,434	5,421	94,239	,434	5,421	94,239
7	,287	3,583	97,822	,287	3,583	97,822
8	,174	2,178	100,000	,174	2,178	100,000

Extraction Method: Principal Component Analysis.

Table 5.27. PCA results for the socio-economic sub-system.

The scree plot representation confirms the results of the PCA as no clear change in slope is drawn while plotting eigenvalues vs. the component number (graph 5.7).



Graph 5.7. Scree plot, PCA of the socio-economic sub-system.

The rotated component matrix (table 5.28) gives the rotated factor loadings for each variable, i.e. the correlation between variable and component. PCA shows that only one variable is correlated with each component (see values in bold) and that the number of variables is equal to the number of principal components: the system therefore has 8 uncorrelated dimensions.

Rotated Component Matrix[a]

	Component							
	1	2	3	4	5	6	7	8
Zscore(FISHERIES)	**,902**	,065	-,011	,025	,261	-,005	,274	,198
Zscore(PORT)	,062	**,967**	-,004	,029	,138	-,004	,181	,094
Zscore(AQUACULTURE)	-,007	-,005	**,995**	,004	-,004	-,002	-,007	,095
Zscore(TOURISM)	,021	,027	,005	**,995**	,032	,078	,010	,050
Zscore(SHELLFISH)	,323	,199	-,024	,043	**,834**	-,007	,239	,317
Zscore(RECREATION)	-,004	-,004	-,002	,077	-,005	**,997**	-,007	-,005
Zscore(MARINA)	,332	,263	-,013	,011	,235	-,011	**,850**	,205
Zscore(CLEANING)	,291	,153	,193	,092	,409	-,010	,253	**,784**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.

Table 5.28. Rotated factor loadings for the socio-economic sub-system.

Physical sub-system

PCA was run on the three physical sub-system variables. The following tables report the result of the calculation.

While 2 principal components could be extracted, each of them accounts respectively for 56% and 34% of the explained variance. (table 5.29).

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1,700	56,664	56,664	1,700	56,664	56,664	1,004	33,452	33,452
2	1,021	34,028	90,693	1,021	34,028	90,693	,999	33,290	66,742
3	,279	9,307	100,000	,279	9,307	100,000	,998	33,258	100,000

Extraction Method: Principal Component Analysis.

Table 5.29. PCA results for the physical sub-system.

The rotated component matrix (table 5.30) gives the rotated factor loadings for each variable, i.e. the correlation between variable and component. PCA shows that only one variable is correlated with each component (see values in bold) and that the number of variables is equal to the number of principal components: the system therefore has 3 uncorrelated dimensions. The only variable which could be excluded from further data collection is SINUOSITY, as it belongs to the factor which accounts for the smallest variance percentage (9%).

Rotated Component Matrix[a]

	Component		
	1	2	3
Zscore(SLOPE)	**,998**	,044	-,047
Zscore(EXPOSURE)	,060	**,922**	,381
Zscore(SINUOSITY)	-,064	,382	**,922**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Table 5.30. Rotated factor loadings for the physical sub-system.

Ecological sub-system

PCA was run on the three ecological sub-system variables. The following tables report the result of the calculation.

In this case, no principal component could be extracted, as each component accounts respectively for 37%, 33% and 28% of total variance (table 5.31).

Total Variance Explained									
	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1,133	37,766	37,766	1,133	37,766	37,766	1,000	33,334	33,334
2	1,001	33,367	71,133	1,001	33,367	71,133	1,000	33,334	66,668
3	,866	28,867	100,000	,866	28,867	100,000	1,000	33,332	100,000
Extraction Method: Principal Component Analysis.									

Table 5.31. PCA results for the ecological sub-system.

The rotated component matrix (table 5.32) gives the rotated factor loadings for each variable, i.e. the correlation between variable and component. PCA shows that only one variable is correlated with each component (see values in bold) and that the number of variables is equal to the number of principal components: the system therefore has 3 uncorrelated dimensions.

Rotated Component Matrix[a]			
	Component		
	1	2	3
Zscore(AFFECTION)	**,999**	,002	,051
Zscore(CONSERVATION)	,002	**,999**	-,043
Zscore(SINGULARITY)	,051	-,043	**,998**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.			
a. Rotation converged in 4 iterations.			

Table 5.32. Rotated factor loadings for the ecological sub-system.

5.8.4 Results

Multivariate analysis for data reduction using PCA demonstrated that no effective data reduction can be performed on the COSVA database, as the variables are uncorrelated (orthogonal). The results showed that the variables belonging to the first principal components do not account for the largest possible amount of information in terms of dataset variance. This outcome reflects the valuable work done by the experts who selected variables which are virtually uncorrelated.

5.9 Discussion and conclusions

Coastal management should rely on accessible and cost-effective information. In complex socio-environmental systems, the use of indicators for integrated management, risk assessments, disaster response, monitoring of environmental quality, etc. often directs experts and managers to complex and redundant datasets which may be really expensive to maintain in terms of money and time.

Underlying correlations can be explored using multivariate statistics techniques.

Where complete datasets are not available, missing value analysis techniques are fundamental to filling the gaps: MVA techniques and examples are reported in this chapter.

Principal components analysis was chosen as the most suitable technique for data analysis. PCA analyzes the covariance between *n* variables, and groups them in independent (orthogonal) components which account for the maximum amount of variance. PCA results can be used to reduce complex datasets to more manageable levels by selecting the most representative variables for each component. PCA can also be used to assign weights to the different variables prior to aggregation into intermediate composite indicators or in final indices.

The DEDUCE database of coastal sustainability indicators was used as a first case study. Despite problems of data availability, MVA was used to fill the gaps in the time series of the datasets available after some filtering and adjustments based on expert knowledge. The final results include a substantial reduction (56%) of available variables. Composite indicators for each system goal are also proposed, even if initial lack of data clearly weakens their validity.

A subsequent PCA was carried out on the COSVA database. The 14 available variables, distributed in 3 sub-systems, show a clear lack of because as no principal component could be identified. This result supports the initial selection of variables carried out by the expert team.

CHAPTER 6 – CONCLUSIONS

6.1 Summary of major findings

This thesis focused on the identification of site-specific and problem-oriented sets of indicators, to be used to determine baseline conditions and to monitor the effect of ICZM initiatives.

The approach followed integrates the contribution of coastal experts and stakeholders, systems theory and practice and the use of multivariate analysis techniques to provide a cost-effective set of indicators, with a broad system perspective.

The analysis of the state of the art in chapter 2 was the starting point to introduce coastal complexity and the need for an integrated and systems approach to coastal management, when ICZM initiatives are launched in Europe and the Mediterranean, supporting the need for further research.

The systems approach has been claimed by many authors and coastal policy documents as a broad frame of reference, useful to improve understanding of complex coastal systems and to provide models which include most of the issues at stake. Applied systems science, from industrial engineering to business management, has developed hard and soft approaches to model complex systems and to address a specific system toward a set of objectives. Softer approaches like systems thinking are more suitable to deal with socio-environmental systems and can be used to map system models as a base for further dynamic simulations.

Systems management practice should rely on indicators which can be used to measure the state of the system, monitor its evolution and direct it towards specific objectives. The most advanced and effective indicators system have been developed by disciplines such as econometrics and health science and they are commonly supported by more or less advanced statistical models. This is the case with many indicators such as GDP, the HDI or the ESI. In any case, indicators must be based on system understanding and on system models which can translate the big picture into sets of variables. Different approaches are available to drive the system to a set of variables, such as the PSR of the DPSIR, but different authors argue for more integrated and systems approaches. In the field of ICZM indicators have been used to deal with the measurement of coastal sustainability, progress toward specific management goals in coastal programmes or to measure the performance of problem-oriented systems at the local level; even if the ICZM theory claims for a system's approach, a structured systems approach is not commonly used for the identification of the system's variables. Moreover, the use of multivariate statistics to identify the most suitable set of indicators or to build composite indicators is not a common practice in ICZM.

The revision of the state of the art in ICZM, systems sciences and indicators was the basis for chapter 3, where research was driven by the analysis of the coastal systems, integrating the scientific knowledge of coastal experts with the practical experience of coastal stakeholders. The examples reported in this thesis confirm the idea that most of the situations encountered by integrated coastal management professionals are complex, unstructured problems which need to be addressed using a systematic approach to identify coastal stakeholders, issues and relationships, i.e. the system's structure which determines its behavior. The potential role of coastal stakeholders in projects in Spain, Italy and Egypt was used to test different techniques for the integration of the experts' sectoral knowledge and for stakeholders' identification and involvement. These experiences demonstrated that the knowledge of coastal experts, integrated with stakeholders perception, is essential to clearly formulate problems, and to carry out coastal systems profiling. Despite this, systems tools should be used to clearly identify the variables which really matter inside the system's frame.

Chapter 4 focuses on the systems thinking approach and on the use of techniques such as participatory causal matrices and causal loop diagrams to draft system models and to identify critical variables. The idea of the approach was to deliver a system model based on the contribution of experts and stakeholders, which could be used as a consensus-based shared mental model and to identify critical variables. This model is in practice a network of interconnected variables which represents the system's shared mental based on the contribution of the each person composing the group. A methodology to rank coastal issues in terms of their relevance and impact was also developed and tested in three different case studies: while the first case study is a theoretical model, the other are based on data from two existing projects, in Italy and Egypt, characterized by different scales and problems. Even if a complete group model building exercise was not yet carried out, modeling of the two systems demonstrated how critical variables can be set off by combining the relevance given by stakeholders with the structure of the system itself.

While chapters four addressed participatory system modeling, chapter 5 tested principal component analysis to analyze the system's structure and reduce the number of variables making the system up. Missing values emerged as a relevant issue while preparing matrices for data processing: imputation of missing values, a multivariate technique, was also reviewed and tested on the first case study, based on the DEDUCE experience. The objective of PCA is to explore the underlying structure of the system, to identify the principal components (a linear combination of existing variables) which are geometrically orthogonal and independent, accounting for as much variance as possible in the datasets. The results of the analysis can be used to select the most representative variables to be used as critical indicators. The methodology was tested on two case studies: the first, the DEDUCE database, aimed to represent coastal sustainability in terms of goals and indicators. Despite lack of data and the missing values in the datasets available, PCA showed some degree of correlation and redundancies in the database which allowed significant data reduction. On the other hand, no reduction could be carried out on the COSVA database as the variables analyzed showed almost no correlations.

6.2 Research questions

The specific research questions formulated in section 1.2 were focused on three specific aspects of this broad problem: how to approach an unknown system, how to build system models and how to analyze the system to deliver critical information for management.

These three research questions are answered as follows:

1. How can we explore a coastal system to improve knowledge and understanding of the issues at stake?

When dealing with coastal projects, plans or strategies, problems are often hard to focus, and multiple issues are at stake. Coastal experts and stakeholders play a major role in the identification of coastal issues. Coastal stakeholders should be clearly identified, together with their role and interests, in order to involve them in the whole process. Various participatory techniques are available and can fit different kinds of situations, and some have been developed in this thesis, and tested on real coastal projects, plans and strategies, which are reported as case studies. The results show that the integration of the technical knowledge of coastal experts with the perception of local stakeholders is fundamental in starting an ICZM process and to carry out a preliminary diagnosis of the issues at stake. On the other hand, a good coastal profile is not enough to identify critical variables which can be used to measure the state and progress of the coastal system: the systems approach should be structured to clearly identify system components and relations.

2. How can we build a model of the system based on the contribution of experts and stakeholders?

The review of the state of the art showed that different approaches are available to model coastal systems, ultimately to deliver coastal indicators, which are more or less effective in modeling the system. This thesis considered the systems thinking approach the most appropriate for solving the problem. Group model-building tools, tested on different case studies, have proved to be useful in building a shared mental model of the coastal system. The examples show that coastal issues and variables can be systematically identified and ranked based on the group's work. These results can be used to propose a system model, to reduce the number of issues at stake or to deliver a preliminary set of coastal indicators.

How can we identify the variables which best describes the system in order to use them to design coastal indicators?

Different variables can be considered appropriate to describe a specific feature of the system, but often causality and correlations among them can spread redundancy in the system model. Principal components analysis can be used to analyze the underlying structure of the system and to reveal relationships between groups of variables, by identifying independent (orthogonal) components. The results of the analysis can address the selection of the most significant and independent variables, accounting for the largest amount of information, to be used as a set of critical indicators or to be combined into a final composite index.

6.3 A three-step methodology proposal

A methodology proposal for the identification of problem-oriented sets of indicators summarizes the major findings and results of the research and provides a handy step-by-step route map for coastal specialists and managers.

This road map is intended to be used at different scales (local projects, plans or strategies) and in different geographical, social and environmental contexts; it is especially useful when dealing with uncertainties while working in developing countries, where expert knowledge is often not sufficient to provide a broad understanding of the system analyzed.

A simple example accompanies the reader through the three steps.

6.3.1 Step 1. Problem formulation and identification of coastal stakeholders

Most of the problems we are dealing with in coastal zone management are unstructured: a clear problem formulation includes the identification of the system's components and of the coastal stakeholder who can be affected by future actions.

The identification of coastal stakeholders should be systematic, with the help of the project promoter (the so-called "problem owner") often a public authority or sometimes a private investor. The promoter should be aware of the importance and the advantages of involving people from the beginning: building consensus around coastal initiatives often determines their final success.

Coastal stakeholders can be identified using the so-called hydra model (section 3.4) where each stakeholder identified by the problem owner is asked to identify other potential stakeholders in an iterative process: depending on the type of project, after a few rounds, all stakeholders are identified.

The list of stakeholders should then be classified by assigning roles: stakeholders should be subdivided into (i) those whose interests lie in the coastal zone, including those living there (ii) stakeholders who live off its resources and (iii) those responsible for its management (section 3.5).

Main output of step 1: list of stakeholders classified by role.

Example: the preliminary problem formulation for a coastal stretch leads to the identification of 100 stakeholders.. Based on their relevance and role, only 20 are invited to participate in a workshop to identify coastal indicators, to be used to measure the state of the coast and simulate the effects of a new coastal plan. The criteria for invitation include: responsibility in coastal management, representativity, sector of concern, technical and scientific background.

6.3.2 Step 2. Involvement of coastal experts and stakeholders in system's modeling

Different techniques are available to involve coastal stakeholders, and the choice should be based on the scale of the project and consequently on the number of stakeholders involved.

When the number of identified stakeholders is high, public meetings and workshops are not advisable because of the difficulties in collecting valuable information. The Internet can help solve this problem.

If the number of stakeholders is not high (say less than 20) either because stakeholders are filtered according to responsibilities and representativity or because the real number of stakeholders is low, a public participation workshop can be held.

At the same time, coastal experts from different disciplines should be involved in the participatory workshop, as a way to address and improve public understanding of specific issues. In this sense, experts and stakeholders should be considered part of the same group.

Two different techniques have been explored and improved in this thesis, one of them the public participation factsheet (see section 3.6), and group interaction for system modeling (chapter 4). The latter is more appropriate for identifying key issues (problem-oriented variables) as a base to identify the most appropriate sets of indicators.

Group model building should be systematic, and can be based on techniques as cluster hexagons, participatory causal matrices and causal loop diagrams. These techniques, based on the systems thinking paradigms, drive the group towards a shared mental model of the system where each component is transformed into a variable according to the contribution of all those involved. These results also yield information about the importance given by each stakeholder (or expert) to the variables, and can be used as a preliminary set of indicators.

Main output of step 2: preliminary set of problem-oriented indicators

Example (continued from step 1): twenty stakeholders are invited to participate in a group model-building workshop. After a brief note regarding the methodology and the problems at stake, they are asked to fill colored paper hexagons with the key issues identified and the associated variables. The hexagons return 100 variables (on average 5 per each participant) with 70% of repeated variables: the analyst finally keeps 30 variables for further analysis. Based on the results of the first session, a participatory causal matrix, with 30 variables in rows and columns (30 x 30), is distributed to the participants, to highlight the hypothetical causal relationships between the variables. The completed PCMs are then superimposed and the resulting shared mental model is charted using causal loop diagram notation. The PCMs are transformed into quantitative results and a first ranking of variables is produced. Most of the importance is assigned to the first 15 variables: this ranking is therefore used as a criterion for the identification of a preliminary set of indicators.

6.3.3 Step 3. Analysis of the system

The first two steps of the methodology proposed are necessary to build a strong theoretical framework, i.e. a model of the system we want to understand, analyze and manage, and a preliminary set of coastal indicators.

The task of stakeholders and experts is to identify components and relations based on their knowledge and experience, but the system model should be further analyzed using quantitative techniques.

Depending on data availability, different quantitative techniques can be used: in data-poor environments, causal loop diagrams can be translated into stock and flow diagrams for systems dynamic simulations to identify the key variables of the system using sensitivity testing.

On the other hand, when data are available, multivariate statistics are a good option to improve system understanding. Techniques such as principal component analysis, factor analysis and structural equation modeling are available to explore redundancies, correlations and causalities.

Principal components analysis was tested in this thesis as a useful technique to analyze data matrices representing the spatial or temporal evolution of the system (chapter 5). PCA returns the analyzed variables, grouping them into *n* orthogonal components where the first one accounts for as much variance as possible in the whole dataset, the second accounts for the second-largest amount of variance, and so on. A fundamental property of PCA is that each component is geometrically orthogonal to the other, ensuring independency between the variables observed. PCA results give information about the relevance of each of the variables analyzed in terms of the variance they account for with each principal component. Variables accounting for the largest amount of information are critical indicators for the system.

<u>Main output of step 3: final set of indicators</u>

Example (continued from step 2): The previously identified 15 variables are quantitatively analyzed to unravel interdependencies and redundancies, to retain the variables which account for the largest amount of information. Data are collected from different sources to build a 20 year time series of the 15 variables. Unfortunately, there are many gaps in the datasets available, and imputation of missing values is necessary to build the 15 x 20 matrix necessary for the analysis. PCA is carried out on the complete matrix, after imputation. Analysis of 15 variables measured over 20 years reveals that 6 variables account for 90% of the information, with a loss of 10%. These 6 variables can then be used as a final set of indicators for the system.

6.4 Drivers for further research

This thesis identified different fields of knowledge and techniques to be used for modeling and simulations of complex unstructured systems in future research, and developed a structured framework for coastal systems' modeling, to be used in ICZM projects. The following ideas represent drivers for future research:

Systems dynamics simulations can be used to analyze the structure and behavior of coastal and water systems and test different alternative scenarios (see for example: Smyth, 2000; Elrefaie, 2005; Khan, 2007; Kojiri, 2008; Zhang et al., 2008). CLD can be formally translated into stock and flow diagrams (Binder, 2008) to carry out simulations. An advantage of SD simulations is that they do not rely on the existence of complete databases (García, 2006) but are based on assumptions of the initial values of key variables.

Structural equation modeling (SEM) can be used to analyze systems structures when data are available. In SEM, causal relationships among the variables in the models are specified and tested with parameter estimation procedures, usually based on maximum likelihood. SEM techniques are typically used to confirm or disprove an *a priori* hypothesized model (see for example, Pugesek et al., 2003; Hurlimann et al., 2008). An example of integration of SEM and CLD is reported by Patel (Patel, 2008). Analysis of the system using SEM could confirm or change the hypothetical model based on stakeholders' mental models and experts' knowledge.

Systems thinking and group model building techniques (PCM and CLD) should be improved and adapted to real cases and projects in the coastal and water management fields. A group model building exercise is being organized to complement the results of the MSICZMP project in Egypt, and is supposed to be carried out during spring 2008.

References

Abel T., 2003. *Understanding complex human ecosystems: the case of ecotourism on Bonaire*. Conservation Ecology 7 (3): 10.

Ackoff R.L., 1974. *The Art of Problem Solving*, Wiley, New York.

Alvarez-Arena M. Mirón, I., 2006. *A flexible framework for regional sustainable development indicators using systems thinking criteria (INSURE)*. Revista Internacional de Sostenibilidad, Tecnología y Humanísmo. n 1 año 2006.

Andersen D.F., Vennix J.A.M., Richardson G.P., Rouwette E., 2007. *Group Model Building: Problem Structuring, Policy Simulation and Decision Supp*ort. The Journal of the Operational Research Society. Oxford: May 2007. 58,5 (691-695).

Antunes P., Santos R., Videira N., 2006. *Participatory decision making for sustainable development—the use of mediated modeling techniques*. Land Use Policy 23 (2006) 44–52.

Areizaga J., Medina R., Sanò M., Juanes J., 2005. *Implementation of the Recommendation 413/2002/EC in Cantabria, Spain*. Eco-imagine: Coastal Governance, Planning and Design and GI, 6th FP Marie Curie Conferences and Training Courses, Nice, France.

Aronson D., 1998. *Overview of Systems Thinking*. The Thinking Page www.thinking.net.

Bald J., Borja A., Muxika I., 2006. *A system dynamics model for the management of the gooseneck barnacle (Pollicipes pollicipes) in the marine reserve of Gaztelugatxe (Northern Spain)*. Ecological modeling 194 (2006) 306-315.

Barragán J.M., 2003. *Coastal Zone Management in Spain (1975-2000)* Journal of Coastal Research, 19-2 314-325.

Barragán J.M., 2004. *Las áreas litorales de España. Del análisis geográfico a la gestión integrada*. Ariel.

Bastianoni S., Pulsellia F.M., Focardia S., Tiezzi E.B.P., Gramatica P., 2008. *Correlations and complementarities in data and methods through Principal Components Analysis (PCA) applied to the results of the SPIn-Eco Project*. Journal of Environmental Management 86 (2008) 419–426.

Vox A., Belyazid S., Haraldsson H., Svensson M. 2008. *Developing Systems Dynamics models from causal loop diagrams*. kwww.inb.uni-luebeck.de/publikationen/pdfs/BiVoBeHaSv04.pdf.

Böhringer C., Jochem P.E.P., 2007. *Measuring the immeasurable - A survey of sustainability indices*. Ecological economics 63 (2007) 1-8.

Bossel H., 1999. *Indicators for Sustainable Development: Theory, Method, Applications. A Report to the Balaton Group*. International Institute for Sustainable Development.

Bots P.W.G., 2002. *Inleiding Technische Bestuurskunde*. Faculteit Techniek, Bestuur en Management, TU Delft, Delft.

Bowen R.E., Riley C., 2003. *Socio-economic indicators and integrated coastal management*. Ocean & Coastal Management 46 (2003) 299–312.

Breton F., Gilbert C., Martí X., 2006. *Report on the use of the ICZM indicators from the WG-ID*. European Environment Agency.

Bryson J.M., 2004. *What to do when stakeholders matter*. Public Management Review. Vol. 6 Issue 1 2004 21–53.

Cabrera D. et. al, 2008. *Systems Thinking*. Evaluation and Program Planning 31 (2008) 299–310.

Castro-Boñano J.M., 2002. *Indicadores de deasrrollo sostenible urbano. Una aplicación para Andalucía*. Tesis Doctoral, Universidad de Málaga.

Cavana R.Y., Maani K.E., 2000. *A Methodological Framework for Systems Thinking and Modeling (ST&M) Interventions.* 1st International conference on Systems Thinking in Management.

Chan S.L., Huang S.L., 2004. *A systems approach for the development of a sustainable community — the application of the sensitivity model (SM)*. Journal of Environmental Management Volume 72, Issue 3, September 2004, Pages 133-147.

Checkland, 1981. *Systems Thinking, Systems Practice*, Wiley.

Chua T.E., 2006. *The Dynamics of Integrated Coastal Zone Management. Practical Applications in the Sustainable Coastal Development in East Asia*. 468 pp. GEF/UNDP/IMO PEMSEA, Quezon City, Philippines.

Cicin-Sain B., Knecht R., 1998. *Integrated Coastal and Ocean Management. Concepts and practices*. Island Press.

Clark J.R., 1996. *Coastal Zone Management Handbook*. CRC Press.

Clayton A.M.H, 1996. *Sustainability: A Systems Approach*. Earthscan.

Conway G., 2007. *Monitoring the state of the Solent*. Marine Policy 31 (2007) 632–637.

Costanza R., 1996. *Modeling Complex Ecological Economic Systems: Towards an Evolutionary Understanding of People and Nature.* In: Ecosystem Management, Selected Readings. Springer.

EC, 1999. *The EC Demonstration Programme on ICZM, 1996-1999*. http://ec.europa.eu/environment/iczm/demopgm.htm.

EC, 2002. *Recommendation of the European Parliament and of the Council concerning the implementation of Integrated Coastal Zone Management in Europe (413/2002/EC).*

EC, 2004. *EUROSION: Living with coastal erosion in Europe: Sediment and Space for Sustainability*.

EC, 2009. *Council Decision of 4 December 2008 on the signing, on behalf of the European Community, of the Protocol on Integrated Coastal Zone Management in the Mediterranean to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (2009/89/EC).*

Economist Intelligence Unit (EIU), 2008. *World Economic Data and Forecasts*. eiu.com/WorldData.

Ehler C.N., 2003. *Indicators to measure governance performance in integrated coastal management*. Ocean & Coastal Management 46 (2003) 335–345.

Elias A.A., 2006. *Environmental Conflicts, Stakeholders and a Shared Mental Model*. Systems Dynamics Society 2006 Conference, Nijmegen, The Netherlands.

Elrefaie M., 2005. *An Integrated Approach for Sustainability Assessment of Tourism Development in Sharm El-Sheikh*. Conference on Development and Tourism in Costal Areas, Sharm El Sheikh, Egypt, 2005.

Enserink B., 2005. *Public Participation in Dutch Watermanagement: Pragmatism in meeting EU requirements*, In: Peter H. Feindt and Jens Newig, 2005. Partizipation, Öffentlichkeitsbeteiligung, Nachhaltigkeit. Perspektieven der Politischen Ökonomie. "Ökologie und Wirtschaftsforschung" — Band 62 Metropolis Verlag, Marburg, ISBN 3-89518-517-5. pp.203-227.

Espinosa A., Harnden R., Walker J., 2008. *A complexity approach to sustainability – Stafford Beer revisited*. European Journal of Operational Research, Volume 187, Issue 2, 1 June 2008, Pages 636-651.

Esty D.C., Kim C., Srebotnjak T., Levy M.A., Sherbinin A., Mara V., 2005. *Environmental Sustainability Index: Benchmarking National Environmental Stewardship*. New Haven: Yale Center for Environmental Law & Policy.

Eurostat, 2009. *Structural Indicators*. www.ec.europa.eu/eurostat/

Fernández F., Pombo C., Castanedo S., Medina R., Juanes J., 2007. *Building The Cantabrian Coast Oil Spill Vulnerability Atlas (Bay Of Biscay)*. CoastGIS07 8th International Symposium on GIS and Computer Mapping for Coastal Zone Management. ISBN 978-84-8102-471-5.

Fontalvo-Herazo M.L., Glaser M., Lobato-Ribeiro A., 2007. *A method for the participatory design of an indicator system as a tool for local coastal management*. Ocean & Coastal Management 50 (2007) 779–795.

Forrester J.W., 1968. *Principles of systems*. Pegasus.

Freeman R.E., 1984. *Strategic Management: A stakeholder approach*. Boston: Pitman.

Gallopín G., 2003. *A systems approach to sustainability and sustainable development.* ECLAC/ Government of the Netherlands Project NET/00/063 "Sustainability Assessment in Latin America and the Caribbean".

García E., De la Hoz D., Sanò M., González M., 2008. *Metodología para la integración de la participación pública con la planificación tradicional en el contexto de la Directiva Marco Europea de Aguas*. XXIII Congreso Latinoamericano de hidráulica Cartagena de Indias Colombia, septiembre 2008.

García J.M., 2006. *Theory and practical exercises of Systems Dynamics*. ISBN 84-6099804-5.

Generalitat de Catalunya, 2006. *Pla director urbanistic del sistema costaner*. www.gencat.net.

Generalitat de Catalunya, Departament de Medi Ambient, 2008. *Indicadores de las zonas costeras*. http://mediambient.gencat.cat/.

Gobierno de Cantabria, 2004. *Plan de Ordenación del Litoral*. www.gobcantabria.es.

Gobierno del Principado de Asturias, 2005. *Plan de Ordenación del Litoral Asturiano*. www.princast.es.

Greenpeace, 2005. *Destrucción a toda Costa. Informe sobre la situación del litoral español.*

Hanson A.J., 2003. *Measuring progress towards sustainable development*. Ocean & Coastal Management, Volume 46, Issues 3-4, Pages 381-390.

Henocque Y., 2003. *Development of process indicators for coastal zone management assessment in France*. Ocean & Coastal Management 46 (2003) 363-379.

Hjorth P., Bagheri A., 2006. *Navigating towards sustainable development: a Systems Dynamics approach*. Futures 38 (2006) 74-92.

Hodgson A.M., 1992. *Hexagons for Systems Thinking*. European Journal of Systems Dynamics Volume 59, No 1, 1992.

Hoffmann J., 2007. *Problem-oriented indicators for an ICZM in the Oder Estuary*. Coastal development: The Oder estuary and beyond. Coastline Reports 8 (2007), ISBN 978-3-9811839-0-0.

Holland J.H., 1975. *Adaptation in Natural and Artificial Systems.* University of Michigan Press.

Hotelling H., 1933 *Analysis of a complex of statistical variables into principal components*. J Educ Psychol 1933; 24: 417-441.

Hurlimann A., Hemphill E., McKay J., Geursen G., 2008. *Establishing components of community satisfaction with recycled water use through a structural equation model.* Journal of Environmental Management, Volume 88, Issue 4, September 2008, Pages 1221-1232.

IH Cantabria, 2007. *Technical report: Matrouh-Sallum ICZM Project Final Report for Phase I.* Report prepared for AECID, Spain and EEAA, Egypt.

IH Cantabria, 2008. *Coastal restoration project for the Finale Ligure Municipality, Italy*. Technical Report on the seasonal nourishment.

INE (Instituto Nacional de Estadística), 2006. *Padrón municipal referido al año 2005*. www.ine.es.

Jackson M.C., 2000. *Systems Approaches to Management.* Springer.

Jiménez J.A., Van Koningsveld M., 2004. *Coastal State Indicators: a bridge between science and coastal management*. Coastview Project Report.

Junninen H., Niska H., Tuppurainen K., Ruuskanen J., Kolehmainen M., 2004. *Methods for imputation of missing values in air quality data sets*. Atmospheric Environment 38 (2004) 2895–2907.

Junta de Andalucía, 2007. *Estrategia Andaluza de Gestión Integrada de Zonas Costeras*. www.juntadeandalucia.es.

Kay R., Alder J., 2005. *Coastal Planning and Management, 2nd Edition*. Taylor & Francis.

Kay R., Alder J., Brown D., Houghton P., 2003. *Management Cybernetics: A New Institutional Framework for Coastal Management.* Coastal Management, Volume 31, Number 3, July-August 2003, pp. 213-227(15).

Kelly K.L., 1998. *A systems approach to identifying decisive information for sustainable development*. European Journal of Operations Research 109 (1998) 452-464.

Ketchum B.H. (ed), 1972. *The water's edge: critical problems of the coastal zone*. In proceedings of the Coastal Zone Workshop, Woods Hole, Massachusetts, 22 May - · June 1972, MIT Press, Cambridge, MA.

Khan S., 2007. *Analysing complex behavior of hydrological systems through a system dynamics approach*. Environmental Modeling & Software (Article in press).

Kiousopulos J., 2005. *Spatial indicators system for Hellenic coastal areas: methodological issues and proposals concerning the coastal planning at the local level*. Eco-imagine: Waterfront Management and GI, 6th FP Marie Curie Conferences & Training Courses, Lisbon, Portugal. 31 of May – 6 of June 2005.

Kojiri T., 2008. *World continental modeling for water resources using system dynamics*. Physics and Chemistry of the Earth 33 (2008) 304–311.

Kopfmüller, J.; Brandl V.; Jörissen J., Paetau M.; Banse G.; Coenen R.; Grunwald A., 2001. *Nachhaltige Entwicklung integrativ betrachtet*. Konstitutive Elemente, Regeln, Indikatoren, Berlin.

Lasaponara R., 2006. *On the use of principal component analysis (PCA) for evaluating interannual vegetation anomalies from SPOT/VEGETATION NDVI temporal series*. ecological modeling 194 (2006) 429–434.

Little R. J. A., Rubin D. B., 1987. *Statistical analysis with missing data*. John Wiley & Sons, New York.

Martí X., Lescrauwaet A., Borg M., Valls M., 2006. *Indicators guideline: to adopt and indicator-based approach to evaluate coastal sustainable development*. DEDUCE Project www.deduce.eu.

Martí X. Prats, F., Del Pozo M., Medina R., Sanò M., Borja A., Bernabeu A., Fernández Y., Bueno J.L., Dietrich A., Vizoso G. 2007. *Grupo de Trabajo sobre Indicadores: Informe de Avance de Resultados. Elaboracion de indicadores de sostenibilidad para el litoral espanol*. (internal report, Ministry of the Environment).

Mayer I.S., Van Daalen C.E., Bots P.W.G.., 2004. *Perspectives on policy analyses: a framework for understanding and design*. Int. J. Technology, Policy and Management, Vol. 4, No. 2, 2004.

Mc Loughlin J.B., 1969. *Urban and Regional Planning: a systems approach*. Faber & Faber, London.

Meadows D.H. Meadows D.L., Randers J., Behrens W.W., 1972. *The Limits to Growth*. Universe Books.

Medina E., 2006. *Designing Freedom, Regulating a Nation: Socialist Cybernetics in Allende's Chile*. J. Lat. Amer. Stud. 38, 571–606 f Cambridge University.

Ministerio de Medio Ambiente, 2006. *Gestión Integrada de las Zonas Costeras en España.*

Nardo M. Nardo M., Saisana M., Saltelli A., Tarantola S., 2005. *Handbook on constructing composite indicators: methodology and user guide.* OECD Statistics Working Paper, 2005.

Newman J., Velasco M.A., Martin L., Fantini A.M., 2003. *A system dynamics approach to monitoring and evaluation at the country level: an application to the evaluation of malaria-control programs in Bolivia.* Fifth Biennial World Bank Conference on Evaluation and Development "Evaluating Development Effectiveness: Challenges and the Way Forward" Washington, D.C. 15-16 July 2003.

Nicoletti G., Scarpetta S., Boylaud O., 2000. *Summary indicators of product market regulation with an extension to employment protection legislation.* OECD, Economics department working papers Nº 226, ECO/WKP(99)18. http://www.oecd.org/eco/eco.

NOAA-OCRM, 2007. *Coastal Zone Management Act Performance Measurement System: Contextual Indicators Manual.* Working Draft.

Nutt P.C., 2002. *Why Decisions Fail: Avoiding the Blunders and Traps that Lead to Debacles.* Berrett-Koehler Publishers.

Odum H.T., 1983. *Systems Ecology: an introduction.* Wiley.

Olsen S., 2003. *Frameworks and indicators for assessing progress in integrated coastal management initiatives.* Ocean & Coastal Management 46 (2003) 347–361.

Organization for Economic Co-operation and Development (OECD), 2008. *Key Environmental Indicators 2008.*

Özesmi U., Özesmi S.L., 2004. *Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach.* Ecological Modeling 176 43–64.

Pahl-Wostl C., 2007. *The implications of complexity for integrated resources management.* Environmental Modeling & Software, Volume 22, Issue 5, May 2007, Pages 561-569.

Papalexandris A., Ioannou G., Prastacos G., Soderquist K.E. 2005. *An Integrated Methodology for Putting the Balanced Scorecard into Action.* European Management Journal Vol. 23, No. 2, pp. 214–227, 2005.

Patel B., Chaussalet T. and Millard P. 2008. *Balancing the NHS balanced scorecard!* European Journal of Operational Research 185 (2008) 905–914.

Peters W.S., Butler J.Q., 1970. *The construction of regional economic indicators by principal components*. The Annals of Regional Science, Volume 4, Number 1 / June, 1970.

Pickaver A.H., Gilbert C., Breton F., 2004. *An indicator set to measure the progress in the implementation of Integrated Coastal Zone Management in Europe.* Ocean & Coastal Management 47 449-462.

Potts T., 2006. *A framework for the analysis of sustainability indicator systems in fisheries*. Ocean & Coastal Management, Volume 49, Issues 5-6, 2006, Pages 259-280.

Pugesek B., Tomer A., Von Eye A., 2003. *Structural Equation Modeling: Applications in Ecological and Evolutionary Biology*. Cambridge University Press.

Reed M., Franser E.D.G., Morse S., Dougill A.J., 2005. *Integrating Methods for Developing Sustainability Indicators to Facilitate Learning and Action*. Ecology and Society 10(1).

Rey-Valette H., Damart S., Roussel S., 2007. *A multicriteria participation-based methodology for selecting sustainable development indicators: an incentive tool for concerted decision making beyond the diagnosis framework*. Int. J. Sustainable Development Vol. 10, Nos 1/2, 2007.

Rice J., 2003. *Environmental health Indicators*. Ocean & Coastal Management 46 (2003) 235–259.

Richardson G.P., Andersen D.F., 1995. *Teamwork in Group Model Building*. System Dynamics Review 11(2):113-137.

Ronchi E., Federico A., Musmeci F., 2002. *A system oriented integrated indicator for sustainable development in Italy*. Ecological Indicators 2 (2002) 197-210.

Royer D.L. Berner R.A., Park J., 2007. *Climate sensitivity constrained by CO2. Concentrations over the past 420 million years*. Nature, Vol. 446 29 March 2007 doi:10.1038/nature05699.

Rupprecht Consult & International Ocean Institute, 2006. *Evaluation of Integrated Coastal Zone Management in Europe*. Final Report.

Sanò M., Fernández F., Gonzalez-Riancho P., Medina R., 2007. *GIS Implementation for ICZM in the Mediterranean Coast of Egypt*. CoastGIS07 8th International Symposium on GIS and Computer Mapping for Coastal Zone Management. ISBN 978-84-8102-471-5.

Sanò M., González-Riancho P., Medina R., 2009. *The Spanish Strategy for Coastal Sustainability: An initiative for ICZM*. Submitted to: Coastal Management Journal, Taylor & Francis (Under revision).

Sanò M., Medina R., Peña C., Fernández J., 2006. *Implementing ICZM in Spain: the Master Plan for Coastal Sustainability*. Littoral 2006, Coastal Innovations and Initiatives. pp. 103-113. ISBN 83-88617-03-6.

Sanò M., Areizaga J., Gonzalez-Riancho P., Juanes J., Medina R., Peña, C., 2007. *El Inventario Nacional De Actores, Leyes e Instituciones para la Gestión Integrada de Las Zonas Costeras*. IX Jornadas Españolas de Puertos y Costas. San Sebastián, Spain, 29-30 of May 2007.

Santoro F.M., 2007. *Implementing participatory coastal management: e-COAST*. Amsterdam Conference on the Human Dimensions of Global Environmental Change, 2007.

Sardá R., Avila C., Mora J., 2005. *A methodological approach to be used in Integrated Coastal Zone Management processes: the case of the Catalan Coast (Catalonia, Spain)*. Estuarine, Coastal and Shelf Science 62 427–439.

Scottish Executive Central Research Unit, 2001. *Indicators to monitor the progress of Integrated Coastal Zone Management: a review of worldwide practice.*

Senge P., 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday/Currency.

Shi C., Hutchinson S.M., Xu S., 2004. *Evaluation of coastal zone sustainability: an integrated approach applied in Shanghai Municipality and Chong Ming Island*. Journal of Environmental Management, Volume 71, Issue 4, July 2004, Pages 335-344.

Smyth R.E., 2000. *Applying Systems Thinking to Catchment Management*. International Conference on Systems Thinking in Management 2000.

SPICOSA WP3, 2007. *System Design, v.1.26*. Napier University, Edinburgh.

Sterman J.D., 2000. *Systems Dynamics. Systems Thinking and modeling for a complex world*. McGraw Hill.

Sterman, J.D., 2008. *Risk Communication on Climate: Mental Models and Mass Balance*. Science Vol. 322 October 2008.

Suárez de Vivero J.L., Rodríguez Mateos J.C., 2005. *Coastal Crisis: The Failure of Coastal Management in the Spanish Mediterranean Region*. Coastal Management 33 197-214.

Thissen W.A.H. Enserink B., Koppenjan J.F.M., Kamps D.P., Bekebrede G., Hermans L., Kwakkel J., 2008. *Advanced Policy Analysis*. TUDelft Faculty of Technology, Policy and Management.

UN, 1992. *United Nations Conference on Environment & Development, Agenda 21, chapter 17.*

UN, 2008. *Atlas of the Ocean*. www.oceanatlas.org.

UNEP, 2008. *Protocol on Integrated Coastal Zone Management in the Mediterranean.*

UNDP, 2009. *Statistics of the Human Development Report* http://hdr.undp.org/en/statistics/

UNEP/MAP, 2008. *Union for the Mediterranean Launched in Paris*. MAP Press Release, 14/07/2008.

UNESCO/IOC, 2003. *A reference Guide on the use of Indicators for Integrated Coastal Management*. ICAM Dossier 1, IOC Manuals and Guides No. 45. UNESCO 2003 (English).

UNESCO/IOC, 2006. A *Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management*. IOC Manuals and Guides, 46; ICAM Dossier, 2. Paris, UNESCO, 2006 (English).

Utne I.B., 2006. *Systems engineering principles in fisheries management*. Marine Policy 30 (2006) 624–634.

Vallega A., 1992. *The management of the Mediterranean sea: the role of regional complexity*. Ocean & Coastal Management, Volume 18, Issues 2-4, 1992, Pages 279-290.

Vallega A., 1999. *Fundamentals of Integrated Coastal Management*. Kluwer.

Van der Weide J., 1993. A *systems view of integrated coastal management*. Ocean & Coastal Management, Volume 21, Issues 1-3, 1993, Pages 129-148.

Van Koningsveld M., 2003. *Matching Specialist Knowledge with End User Need. Bridging the gap between coastal science and coastal management.* PhD Thesis. Universiteit Twente.

Varghese K., Ganesh L.S., Mani M., Anilkumara P.P., Murthyd R., Subramaniam B.R., 2008. *Identifying critical variables for coastal profiling in ICZM planning—A systems approach*. Ocean & Coastal Management, Volume 51, Issue 1, 2008, Pages 73-94.

Vella L., 2002. *CAMP Malta*. in Coastal Area Management Programmes: Improving the Implementation: MAP/PAP/METAP Workshop Malta, 17-1 9 January 2002.

Vennix J., 1999. *Group model-building: tackling messy problems*. System Dynamics Review 15 (4), 379–401.

Von Bertalanffy L., 1968. *Gentrol and communication in the animal and the machine*. The MIT Press.

Von Bertalannfy L., 1968. *General System Theory: foundations, development, application*. George Brazillier Ed., New York.

Wiener N., 1948. *Cybernetics. or Control and Communication in the Animal and the Machine.* The MIT Press.

World Health Organization (WHO), 2008. *WHO Statistical Information System (WHOSIS)* http://www.who.int/whosis/en/.

Zhang X.H., Zhang, H.W., Chen B., Chen G.Q., Zhao X.H., 2008. *Water resources planning based on complex system dynamics: A case study of Tianjin city*. Communications in Nonlinear Science and Numerical Simulation 13 (2008) 2328–2336.

A note on software

Some of the analyses described in the present thesis have been done using common software packages (MS Excel, MS Access, ESRI ArcGIS 9) while other specific tasks have been supported by specific software:

- VENSIM PLE was used for the construction of CLDs.
- SPSS was used to perform PCA and imputation of missing values.

While VENSIM PLE can be used to carry out further research in systems dynamics, AMOS, an SPSS extension, can be used to perform SEM simulations.

ANNEX I – The DEDUCE Database

This annex reports The DEDUCE database before and after imputation (see section 5.7.2 and 5.7.3 for details).

	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	2.1.1	2.1.2	2.1.3	3.1.1	3.1.2	4.1.1	4.1.2	5.1.1	6.1.1	6.1.2
	COAST POP	PERCC OASTP OP	DENSIT Y	PRICEH OUSES	PRICE2 NDHOU SES	BUILTU PLAND 1KM	BUILTU PLAND 10KM	BUILTU PLAND CM	AREA_ NON_B UILT_C M	INCRE ASE_B UILT_U P	HIGHW AYSTR ANSITS	ROADS TRANSI TS	MOORI NGS	AGRIL AND	INTENS EAGRIL AND
1980															
1981	2802858,00	0,47	1295,93												
1982													14539,00		
1983															
1984															
1985											91767,00	10632,18			
1986	2784354,00	0,47	1287,38												
1987						0,25	0,10	0,13	0,87					41601,90	78494,40
1988															
1989															
1990											170528,00				
1991	2774951,00	0,46	1283,03								194401,00	17228,99			
1992						0,30	0,13	0,16	0,84	0,01			22352,00	44564,80	77635,80
1993															
1994															
1995											205141,00				
1996	2709301,00	0,44	1252,68								210640,00	19707,43			
1997						0,33	0,15	0,18	0,82	0,01			25148,00	40353,40	71204,30
1998				1371,09	1111,88										
1999				1464,80	1259,30										
2000				1628,43	1524,97						324625,00		26242,00		
2001	2795175,00	0,44	1292,38	1874,26	1739,01						346333,00	21693,16			
2002				2239,36	1933,60	0,35	0,16	0,19	0,81	0,00				40502,70	69961,00
2003				2537,37	2288,19										
2004				3318,30	2935,73								28429,00		
2005	3024915,00	0,43	1398,60	4147,17	3331,83						416285,43	22768,72	28969,00		
2006															

	7.1.1	7.1.2	7.1.3	8.1.1	8.1.2	9.1.1	10.1.1	10.2.1	10.3.1	10.3.2	10.3.3	11.1.1	12.1.1	12.2.1	13.1.1	13.2.1	13.3.1	14.1.1	14.2.1	15.1.1	15.2.1	16.1.1	17.1.1	18.1.1
	NATINCM	NATIN1	NATIN10	MPA	PA_IN_10	N/A	N/A	N/A	NUM_MAR_SPEC	NUM_MAR_SPEC_IUCN	PERC_MAR_SPEC_IUCN	PERC_LOC_PROD	EMPLOYMENT	N/A	N/A	N/A	GOODS_SEA	N/A	N/A	N/A	N/A	QUALBATHWATER	LITTER	NITRATES
1980																								
1981																								
1982																								
1983																								
1984																								
1985																								
1986													0,47											
1987	0,51	0,51	0,52																					
1988																								
1989																								
1990																						0,90		
1991													0,55									0,91		
1992	0,48	0,45	0,49																			0,89		
1993																						0,93		
1994																						0,97		
1995																						0,98		
1996													0,52									0,98		
1997	0,48	0,46	0,50														0,20					0,98		
1998									23,00	7,00	0,30						0,17					0,98		
1999																	0,18					0,99		5,04
2000									29,00	12,00	0,41						0,16					0,98		1,76
2001													0,63				0,16					0,98		
2002	0,48	0,46	0,49						29,00	12,00	0,41						0,16					1,00	1,53	
2003																	0,16					1,00	1,74	9,25
2004									29,00	13,00	0,45						0,16					1,00	1,55	4,78
2005				0,05	0,22																		1,96	5,25
2006									32,00	17,00	0,53	0,28												

	18.1.1	18.1.2	19.1.1	19.1.2	19.2.1	20.1.1	21.1.1	21.1.2	21.2.1	22.1.1	23.1.1	23.2.1	23.3.1	24.1.1	25.1.1	25.2.1	25.3.1	26.1.1	26.2.1	26.2.2	27.2.1	27.2.1
	NITRATES	PHOSPHATES	OIL_MC	OIL_L	SLICKS	N/A	INCOMECM	INCOMEPCCM	HIGHEDU	FIRST2NDHOUSE	OVER_FISH	LANDINGFISH	LANDING_FISH_VALUE	WATER_SUPL	WAVES	SEALEVEL	COAST_INFRA	COAST_ERO	SAND_VOL	SAND_LEN	POP_RISK	PA_RISK
1980																						
1981									198571,00	0,22												
1982																						
1983																			25,27	1600,00		
1984																			191,43	2400,00		
1985																			0,00	0,00		
1986									219687,00										1706,88	10800,00		
1987																			4547,22	22700,00		
1988																			556,43	12450,00		
1989																			0,00	0,00		
1990												26428,51				6992,92			230,05	1700,00		
1991							20283500,00	7309,50	272735,00	0,27		25917,10			41,72	6991,92			771,16	14250,00		
1992												27817,92			71,58	6990,92			3755,43	11000,00		
1993												54858,59			33,46	7002,50			3681,38	15478,00		
1994												66321,67			26,62	7009,92			4122,91	13750,00		
1995												63147,94			37,29	7010,50			0,00	0,00		
1996							25713100,00	9490,68	320370,00			52921,86			49,29	7069,50			0,00	0,00		
1997												47775,94	135705051,62			7058,92	0,12		0,00	0,00		
1998												40971,13	127848728,88			7022,92			400,00	4000,00		
1999	5,04	0,15			20,00							43678,79	125448144,09			7015,50						
2000	1,76	0,14			49,00		33477114,00	12073,85				44672,99	132662961,52			7019,00						
2001					30,00				399285,00	0,27	0,50	43834,15	138944151,68		44,81	7049,50						
2002			9,00	15,52	46,00						0,50	36802,80	137683266,12		47,38	7065,08						
2003	9,25	0,19	7,80	13,45	30,00						0,50	33572,88	129761962,29		85,50	7072,08						
2004	4,78	0,19	3,75	6,47	46,00						0,33	33681,28	123645269,90		36,47			0,33				
2005	5,25	0,26	2,22	3,83							0,57	32879,29	116042412,11	0,00	11,84						0,43	
2006														0,00								0,07

	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	2.1.1	2.1.2	2.1.3	4.1.1	4.1.2	5.1.1	6.1.1	6.1.2	7.1.1	7.1.2	7.1.3	12.1.1	16.1.1	18.1.1	18.1.2	21.1.1	21.1.2	21.2.1	22.1.1	23.2.1	25.1.1	25.2.1
	COASTPOP_1	PERCCOASTPOP_1	DENSITY_1	PRICEHOUSES_1	PRICE2NDHOUSES_1	BUILTUPLAND1KM_1	BUILTUPLAND10KM_1	BUILTUPLANDCM_1	HIGHWAYSTRANSITS_1	ROADSTRANSITS_1	MOORINGS_1	AGRILAND_1	INTENSEAGRILAND_1	NATINCM_1	NATIN10_1	NATIN1_1	EMPLOYMENT_1	QUALBATHWATER_1	NITRATES_1	PHOSPHATES_1	INCOMECM_1	INCOMEPCCM_1	HIGHEDU_1	FIRST2NDHOUSE_1	LANDINGFISH_1	WAVES_1	SEALEVEL_1
1981	2802858,00	0,47	1295,93	235,00	180,00	0,19	0,60	0,20	75343,00	5668,00	13465,00	44584,00	83225,00	0,54	0,58	0,56	0,42	0,72	3,81	0,08	10457898,00	2435,00	198571,00	0,22	20487,46	33,00	6932,00
1982	2799157,20	0,47	1294,22	257,50	205,00	0,20	0,52	0,19	79449,00	6909,04	14539,00	44086,98	82436,57	0,53	0,57	0,55	0,43	0,75	3,89	0,08	11424029,50	3007,67	202794,20	0,23	20809,09	39,00	6935,67
1983	2795456,40	0,47	1292,51	280,00	230,00	0,21	0,43	0,18	83555,00	8150,09	15320,30	43589,97	81648,13	0,53	0,56	0,55	0,44	0,78	3,98	0,09	12390161,00	3580,33	207017,40	0,23	21130,71	45,00	6939,33
1984	2791755,60	0,47	1290,80	302,50	255,00	0,22	0,35	0,16	87661,00	9391,13	16101,60	43092,95	80859,70	0,52	0,54	0,54	0,45	0,80	4,06	0,09	13356292,50	4153,00	211240,60	0,23	21452,34	51,00	6943,00
1985	2788054,80	0,47	1289,09	325,00	280,00	0,23	0,27	0,15	91767,00	10632,18	16882,90	42595,93	80071,27	0,52	0,53	0,53	0,46	0,83	4,14	0,09	14322424,00	4725,67	215463,80	0,24	21776,66	48,00	6955,67
1986	2784354,00	0,47	1287,38	354,75	303,75	0,24	0,19	0,14	107519,20	11731,65	17664,20	42098,92	79282,83	0,51	0,52	0,52	0,47	0,84	4,23	0,10	15288555,50	5298,33	219687,00	0,24	22100,99	45,00	6968,33
1987	2782473,40	0,46	1286,51	384,50	327,50	0,25	0,10	0,13	123271,40	12831,12	18445,50	41601,90	78494,40	0,51	0,51	0,52	0,49	0,86	4,31	0,10	16254687,00	5871,00	230296,60	0,25	22425,31	42,00	6981,00
1988	2780592,80	0,46	1285,64	414,25	351,25	0,26	0,11	0,14	139023,60	13930,59	19226,80	42194,48	78322,68	0,50	0,50	0,51	0,50	0,87	4,20	0,10	17261890,25	6230,62	240906,20	0,25	23759,71	41,93	6990,00
1989	2778712,20	0,46	1284,77	444,00	375,00	0,27	0,11	0,14	154775,80	15030,05	20008,10	42787,06	78150,96	0,49	0,49	0,51	0,52	0,89	4,10	0,11	18269093,50	6590,25	251515,80	0,26	25094,11	41,86	6991,00
1990	2776831,60	0,46	1283,90	545,60	470,00	0,28	0,12	0,15	170528,00	16129,52	20789,40	43379,64	77979,24	0,49	0,48	0,50	0,53	0,90	3,99	0,11	19276296,75	6949,87	262125,40	0,26	26428,51	41,79	6992,92
1991	2774951,00	0,46	1283,03	647,20	565,00	0,29	0,12	0,15	194401,00	17228,99	21570,70	43972,22	77807,52	0,48	0,46	0,50	0,55	0,91	3,88	0,12	20283500,00	7309,50	272735,00	0,27	25917,10	41,72	6991,92
1992	2761821,00	0,46	1276,96	748,80	660,00	0,30	0,13	0,16	197086,00	17724,68	22352,00	44564,80	77635,80	0,48	0,45	0,49	0,54	0,89	3,77	0,12	21369420,00	7745,73	282262,00	0,27	27817,92	71,58	6990,92
1993	2748691,00	0,45	1270,89	850,40	755,00	0,31	0,13	0,16	199771,00	18220,37	22911,20	43722,52	76349,50	0,48	0,45	0,49	0,54	0,93	3,67	0,12	22455340,00	8181,97	291789,00	0,27	54858,59	33,46	7002,50
1994	2735561,00	0,45	1264,82	952,00	850,00	0,31	0,14	0,17	202456,00	18716,05	23470,40	42880,24	75063,20	0,48	0,46	0,49	0,53	0,97	3,56	0,13	23541260,00	8618,21	301316,00	0,27	66321,67	26,62	7009,92
1995	2722431,00	0,45	1258,75	1056,75	915,47	0,32	0,14	0,17	205141,00	19211,74	24029,60	42037,96	73776,90	0,48	0,46	0,49	0,52	0,98	3,45	0,13	24627180,00	9054,44	310843,00	0,27	63147,94	37,29	7010,50
1996	2709301,00	0,44	1252,68	1161,50	980,94	0,33	0,15	0,18	210640,00	19707,43	24588,80	41195,68	72490,60	0,48	0,46	0,49	0,52	0,98	3,85	0,14	25713100,00	9490,68	320370,00	0,27	52921,86	49,29	7069,50
1997	2726475,80	0,44	1260,62	1266,25	1046,41	0,33	0,15	0,18	239136,25	20104,58	25148,00	40353,40	71204,30	0,48	0,46	0,50	0,54	0,98	4,25	0,14	27654103,50	10136,47	336153,00	0,27	47775,94	48,40	7058,92
1998	2743650,60	0,44	1268,56	1371,00	1111,88	0,34	0,15	0,18	267632,50	20501,72	25512,67	40383,26	70955,64	0,48	0,46	0,49	0,56	0,98	4,64	0,15	29595107,00	10782,26	351936,00	0,27	40971,13	47,50	7022,92
1999	2760825,40	0,44	1276,50	1465,00	1259,30	0,34	0,15	0,19	296128,75	20898,87	25877,33	40413,12	70706,98	0,48	0,46	0,49	0,59	0,99	5,04	0,15	31536110,50	11428,05	367719,00	0,27	43678,79	46,61	7015,50
2000	2778000,20	0,44	1284,44	1628,00	1524,97	0,34	0,16	0,19	324625,00	21296,02	26242,00	40442,98	70458,32	0,48	0,46	0,49	0,61	0,98	1,76	0,14	33477114,00	12073,85	383502,00	0,27	44672,99	45,71	7019,00
2001	2795175,00	0,44	1292,38	1874,00	1739,01	0,35	0,16	0,19	346333,00	21693,16	26788,75	40472,84	70209,66	0,48	0,46	0,49	0,63	0,98	4,26	0,16	35516775,40	12754,68	399285,00	0,27	43834,15	44,81	7049,50
2002	2852610,00	0,44	1318,94	2239,00	1933,60	0,35	0,16	0,19	363821,11	21962,05	27335,50	40502,70	69961,00	0,48	0,46	0,49	0,68	1,00	6,75	0,17	37556436,80	13435,51	418425,50	0,29	36802,80	47,38	7065,08
2003	2910045,00	0,44	1345,49	2537,00	2288,19	0,36	0,16	0,21	381309,21	22230,94	27882,25	40335,47	68791,67	0,47	0,46	0,49	0,73	1,00	9,25	0,19	39596098,20	14116,34	437566,00	0,31	33572,88	85,50	7072,08
2004	2967480,00	0,43	1372,05	3318,00	2935,73	0,36	0,17	0,22	398797,32	22499,83	28429,00	40168,23	67622,33	0,46	0,46	0,48	0,77	1,00	4,78	0,19	41635759,60	14797,17	456706,50	0,33	33681,28	36,47	7098,54
2005	3024915,00	0,43	1398,60	4417,00	3331,83	0,37	0,17	0,23	416285,43	22768,72	28969,00	40001,00	66453,00	0,45	0,46	0,47	0,82	1,00	5,25	0,26	43675421,00	15478,00	475847,00	0,35	32879,29	11,84	7125,00