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TESIS DOCTORAL

CLASIFICACIÓN FÍSICA DEL INTERMAREAL ROCOSO Y DISTRIBUCIÓN DE MACROALGAS A DIFERENTES ESCALAS ESPACIALES A LO LARGO DEL NE ATLÁNTICO

PhD DISSERTATION

PHYSICAL CLASSIFICATION OF THE INTERTIDAL ROCKY SHORE AND DISTRIBUTION OF MACROALGAE AT DIFFERENT SPATIAL SCALES ALONG THE NE ATLANTIC

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A mis padres

Un científico en su laboratorio no es sólo un técnico,
es también un niño colocado ante fenómenos naturales
que le impresionan como un cuento de hadas.

Marie Curie

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RESUMEN

De acuerdo con la normativa de estudios de doctorado de la Universidad de Cantabria en relación a los requerimientos exigidos para aquellas tesis redactadas en un idioma diferente al español, aprobada por Junta de Gobierno de 12 de marzo de 1999 y actualizada a 18 de diciembre de 2013, a continuación se presenta un resumen "suficientemente extenso" del documento original redactado en inglés.

1. Introducción

1.1. Exposición de motivos

Los ecosistemas costeros se encuentran entre los más productivos y altamente amenazados del planeta (Costanza et al., 1997). Según la Agencia Europea de Medio Ambiente (EEA, 2010), existen evidencias de que la costa Europea está sufriendo un proceso de degradación por diversas causas, como son la pérdida de hábitats, la eutrofización, la contaminación, la erosión o las especies invasoras. Además, muchos de estos impactos se están intensificando recientemente como consecuencia de las variaciones asociadas al cambio climático (e.g., Lozano et al., 2004; Philippart et al., 2011).

Al mismo tiempo, los conflictos entre los usos potenciales y la disponibilidad de espacio hacen esencial el desarrollo de herramientas de gestión, como la Ordenación del Espacio Marítimo o la Gestión Integrada de Zonas Costeras (GIZC), para mejorar la protección de los recursos costeros frente al aumento de su uso. Con el objetivo de promover dicho desarrollo sostenible, la Unión Europea adoptó en 2014 la Directiva 2014/89/UE por la que se establece un marco para la ordenación del espacio marítimo y la Recomendación de 30 de mayo de 2002 sobre la aplicación de la gestión integrada de las zonas costeras en Europa. La ordenación del espacio marítimo cartografía, analiza y organiza las activadas humanas en áreas marinas, a la vez que asegura la conservación y mantenimiento de los ecosistemas. De este modo, la información extensa sobre la biodiversidad en general, y sobre el estado de conservación de las diferentes comunidades y especies que colonizan los fondos marinos en particular, representa un recurso imprescindible a la hora de tomar decisiones en la gestión de este medio.

Como parte del proceso de evaluación y diagnóstico del medio marino surge la necesidad de establecer unidades homogéneas de acuerdo a características físicas y ecológicas, siendo estas unidades los sujetos que deben ser gestionados. En este contexto, diferentes métodos han sido aplicados para clasificar las aguas costeras a lo largo del mundo (e.g., Sherman, 1986; Roff y Taylor, 2000; Mount et al., 2007; Madden et al., 2009). Específicamente en la región del NE Atlántico se han desarrollado varios sistemas de clasificación, el Europeo Paleártico (Devilliers y Devilliers-Terschuren, 1996); CORINE (Commission of the European Communities, 1991); la Directiva Hábitats (1992/43/CEE), basada en la distribución de especies; regiones OSPAR (Dinter, 2001); EUNIS (Davies et al., 2004); las ecoregiones de la Directiva Marco del Agua para aguas costeras y de transición (DMA; 2000/60/CE) y las subregiones de la Directiva Marco sobre la Estrategia Marina (2008/56/CE), ambas basadas en características abióticas; HELCOM del Báltico; y el proyecto BioMar (Connor et al., 1997), que engloba todas ellas. Pese a la existencia de todas estas aproximaciones, los sistemas de clasificación varían mucho dependiendo de la heterogeneidad física y biológica de cada zona y de la disponibilidad de datos. En definitiva, no existe una metodología de clasificación estandarizada que pueda ser utilizada para la conservación y gestión de distintas regiones y a diferentes escalas.

La primera aproximación para realizar una división a nivel mundial se llevó a cabo a través del proyecto Grandes Ecosistemas Marinos (*Large Marine Ecosystems*, LMEs), delimitados en 1984 durante el Simposio Internacional de la Asociación Americana para el Avance de la Ciencia. En la aproximación de los LME se dividen los sistemas del medio marino a nivel mundial, considerando cuatro criterios ecológicos vinculados entre sí: batimetría, hidrografía, productividad y relaciones tróficas. A partir de estos cuatro criterios se distinguen 64 grandes ecosistemas alrededor del mundo (Sherman y Hempel, 2009). Dentro de estos se encuentra la "Costa Ibérica", definida como la región del Nordeste Atlántico correspondiente a la plataforma continental entre el Golfo de Cádiz y el mar Cantábrico, que bordea Portugal y parte de España.

En el territorio Europeo se realizó un inventario de los hábitats existentes a través del proyecto Biotopos CORINE, dentro del programa general CORINE 1985-1990 (*Coordination of Information on the Environment*). Mediante este proyecto se estableció una clasificación jerárquica de los principales tipos de hábitats naturales en función de características fitosociológicas. Más tarde, la clasificación propuesta se revisó y amplió dando como resultado el catálogo *CORINE biotopes manual. Habitats of the European Community* (Devillers et al., 1991).

Para asegurar no sólo el buen estado de las aguas, sino también el mantenimiento de la biodiversidad de los hábitats naturales y de la fauna y flora silvestres, surge la Directiva Hábitats, que recoge la esencia del Convenio de Diversidad Biológica desarrollado en Junio de 1992 en la cumbre de Río de Janeiro. En esta aproximación regional se divide Europa en grandes unidades biogeográficas, dentro de las que cada estado reconoce espacios delimitados que deben ser objeto de protección debido a la presencia de determinados hábitats y especies que requieren una consideración especial en dicho ámbito espacial. Estos son los denominados Lugares de Importancia Comunitaria (LICs). Para ello, se requiere contar con información cartográfica detallada de los diferentes hábitats representados en el litoral y así poder clasificar los LICs según su valor relativo para la conservación.

Sin embargo, el medio marino está poco representado, tanto en la clasificación CORINE como en la Directiva Hábitats, debido a que son clasificaciones basadas principalmente en el conocimiento sobre los ecosistemas terrestres. Así, en el catálogo CORINE, dentro del grupo *Seabed* se subdividen las comunidades bentónicas según profundidad, sustrato, localización geográfica, movimiento del agua y biocenosis, de forma que todo el intermareal queda englobado en la categoría *Cliffs and rocky shores*. Por su parte, en el Anexo I de la Directiva Hábitats, los hábitats del intermareal y submareal se engloban en el tipo *Arrecifes* (código 1170). El Manual de interpretación de los hábitats de la Unión Europea EUR 25 (2003) define los *Arrecifes* como "*sustratos rocosos y concreciones biogénicas submarinas, o expuestas en mareas bajas, que surgen del fondo del mar en la zona sublitoral pero que pueden extenderse hasta la zona litoral donde hay una ininterrumpida zonación de comunidades de plantas y animales. Estos arrecifes normalmente mantienen una zonación de comunidades bentónicas de especies animales* *y vegetales incluyendo concreciones, incrustaciones y concreciones coralígenas*". Estas definiciones tan generalizadas representan una muestra de las lagunas de conocimiento actual sobre las zonas intermareales y submareales someras.

Como prueba de ello, la Decisión de la Comisión de 7 de diciembre de 2004, por la que se aprueba la lista de lugares de importancia comunitaria de la región biogeográfica Atlántica, incluye entre los tipos de hábitats que requieren mayor conocimiento el citado grupo 1170 (Anexo III: Lista de tipos de hábitats y especies, respecto a los cuales no puede afirmarse que la red esté completa o incompleta). Es por ello una necesidad el estudio de los hábitats de *Arrecifes,* con el fin de mejorar los sistemas de identificación precisa de las comunidades, agrupaciones y especies que colonizan dicho ecosistema.

Por otro lado, organizaciones intergubernamentales de ámbito regional (Convenio de Barcelona, Convenio OSPAR, Convenio de Helsinki) y global (Convenio sobre la Diversidad Biológica) también han puesto de manifiesto la carencia existente en la definición de la representatividad de especies y hábitats marinos. Además, surge la necesidad de establecer un sistema de clasificación de los hábitats desde un punto de vista físico, dado que las clasificaciones iniciales estaban fuertemente asentadas en relaciones fitosociológicas, suponiendo un problema para los hábitats no vegetados, como es el caso de gran parte de los ambientes marinos. En este sentido, dentro del marco legislativo de la citada Directiva Hábitats (Anexo I), la Agencia Europea de Medio Ambiente (EEA) desarrolló la clasificación de hábitats EUNIS en respuesta a las propuestas recibidas desde el Comité de Biodiversidad OSPAR y los trabajos elaborados en el Mar Báltico. EUNIS es un sistema de clasificación físico, descriptivo y predictivo que se organiza de forma jerárquica (Davies et al., 2004). El marco de trabajo actual incluye *parámetros*, que se utilizan para distinguir los hábitats, y *parámetros descriptivos,* usados para describir rangos de geomorfología, salinidad, impacto humano y el resto de características que se engloban dentro de un hábitat. Su organización presenta cuatro niveles básicos, siendo en el segundo de dichos niveles donde se distingue entre el tipo de hábitat A1, *Roca litoral y otros sustratos duros,* y el tipo A3, *Roca infralitoral y otros sustratos duros* (siempre cubierto por el agua). Así se marca la diferencia entre la zona intermareal y la submareal. Este sistema representa un marco general cuyo futuro desarrollo es esencial para una implementación efectiva de las distintas Directivas Europeas.

Por su parte, la DMA establece el objetivo de alcanzar para el 2015 un “buen estado ecológico” de todas las masas de agua, incluyendo las de transición y las costeras. Para ello, los Estados Miembros deberán evaluar el Estado Ecológico de las masas de agua, a través de la evaluación de los elementos de calidad biológicos, físico-químicos e hidromorfológicos. Uno de los elementos de calidad biológicos es la vegetación (macroalgas y angiospermas), para cuya evaluación los Estados Miembros han propuesto diferentes metodologías. Por ello, y para asegurar la consistencia entre los diferentes métodos nacionales de evaluación, es necesario llevar a cabo un ejercicio de intercalibración, cuya esencia es asegurar que un buen estado ecológico representa el mismo nivel de calidad a lo largo de toda Europa (Anexo V, DMA).

Para reducir las disimilaridades debidas a grandes gradientes espaciales, la DMA divide Europa en cuatro regiones biogeográficas, siendo una de éstas el Nordeste Atlántico (NEA) (European Commission, 2009a). El NEA es una región muy heterogénea, con aguas costeras que presentan una alta diversidad de macroalgas, desde Noruega hasta Canarias. De forma general, las masas de agua se tipificaron utilizando descriptores obligatorios (amplitud de marea y salinidad) combinados con descriptores optativos (profundidad, velocidad de corriente, exposición al oleaje, características de la mezcla de aguas y tiempo de permanencia) (European Commission, 2009b). No obstante, esta división no era suficiente para recoger la variabilidad de condiciones en una zona tan amplia, por lo que fue necesario la implantación de subtipos, como una tarea urgente y esencial para poder llevar a cabo el ejercicio de intercalibración (European Commission, 2009c).

A tenor de todo lo expresado, se puede observar que las diferentes directivas europeas y convenios internacionales usan diferentes clasificaciones que hacen compleja la gestión de los diferentes objetivos de conservación y mejora de los ecosistemas acuáticos litorales. Además, la gestión y protección de estas áreas costeras tiene lugar a diferentes escalas espaciales (Connor et al., 2006), por lo que la disponibilidad de clasificaciones en diversos ámbitos representa un elemento esencial (Bianchi et al., 2012). Esta característica es particularmente importante en aquellas políticas y planes de gestión que abarcan distinto rango de escalas, con objetivos establecidos a nivel nacional o regional pero implementados en zonas más locales (Rice et al., 2011). Es por ello necesario tratar de establecer un sistema de clasificación homogéneo de éste ambiente a distintas escalas espaciales, que tenga en cuenta tanto las características físicas como las relacionadas con las comunidades biológicas que colonizan dicho entorno. Este sistema serviría como medio para abordar criterios de evaluación y diagnóstico precisos de su estado de conservación que, en última instancia, permitan una gestión sostenible de los mismos al nivel de detalle requerido en cada caso.

1.2. Objetivos

El objetivo general de esta tesis es desarrollar una metodología de clasificación de la costa intermareal rocosa a escala Europea (Nordeste Atlántico), regional (Norte y Noroeste de la Península Ibérica) y local (Cantabria), a través de la relación entre características abióticas y la distribución de especies de macroalgas.

Los objetivos específicos de la tesis se centran en los siguientes aspectos, aplicables a cada una de las escalas espaciales consideradas:

1) Seleccionar las variables físicas más adecuadas y disponibles, y analizar de forma específica como estas influyen en la distribución y estructura de las comunidades de macroalgas intermareales.

2) Elaborar una clasificación cuantitativa de la costa basada en las variables físicas previamente seleccionadas.

3) Analizar y caracterizar la distribución de las especies de macroalgas intermareales a lo largo de la costa, proporcionando información homogénea y estandarizada.

4) Comprobar la concordancia entre la clasificación física y la distribución de macroalgas en la zona intermareal.

1.3. Organización de la tesis

La estructura de la tesis se organiza de la siguiente manera:

En el capítulo I se exponen los motivos por los cuales se ha realizado el presente trabajo de investigación, se describe el estado de conocimiento sobre los diferentes temas tratados en la tesis y se presentan los objetivos específicos diseñados para responder a las cuestiones planteadas.

En los siguientes cinco capítulos (II, III, IV, V y VI) se presentan los estudios desarrollados para la consecución de los objetivos específicos de la tesis. Cada uno de estos cinco capítulos está compuesto por un resumen, una breve introducción que incluye los objetivos específicos de cada estudio y los apartados de metodología, resultados y discusión, constituyendo una versión editada de los artículos ya publicados o en fase de revisión científica en revistas indexadas dentro del SCI. En la Figura 1 se puede observar un resumen gráfico de los resultados obtenidos en estos trabajos:

- *Capítulo II. Clasificación física a escala Europea*. En este capítulo se desarrolla un sistema de clasificación de las aguas costeras basado en variables abióticas a lo largo de la región del Nordeste Atlántico.

- *Capítulo III. Clasificación biológica a escala Europea*. Se realiza una validación biológica para respaldar el significado ecológico de las tipologías físicas obtenidas en el capítulo anterior.

- *Capítulo IV. Clasificación de la costa a escala regional*. Este trabajo propone una metodología de reducción de escala para la clasificación de la línea de costa a lo largo del N y NO de la Península Ibérica.

- *Capítulo V. El papel de la geomorfología en la distribución de macroalgas a escala local*. En este capítulo se analiza la relación entre las variables geomorfológicas (procesos activos, morfología costera, orientación de la costa y litología) y las especies de macroalgas intermareales en sustrato rocoso.

- *Capítulo VI. Clasificación de la costa a escala local*. Se adapta la metodología desarrollada a escalas más amplias para clasificar la costa de Cantabria, completando así un sistema de clasificación jerárquico.

Por último, las conclusiones generales y las futuras líneas de investigación se describen en el capítulo VII.

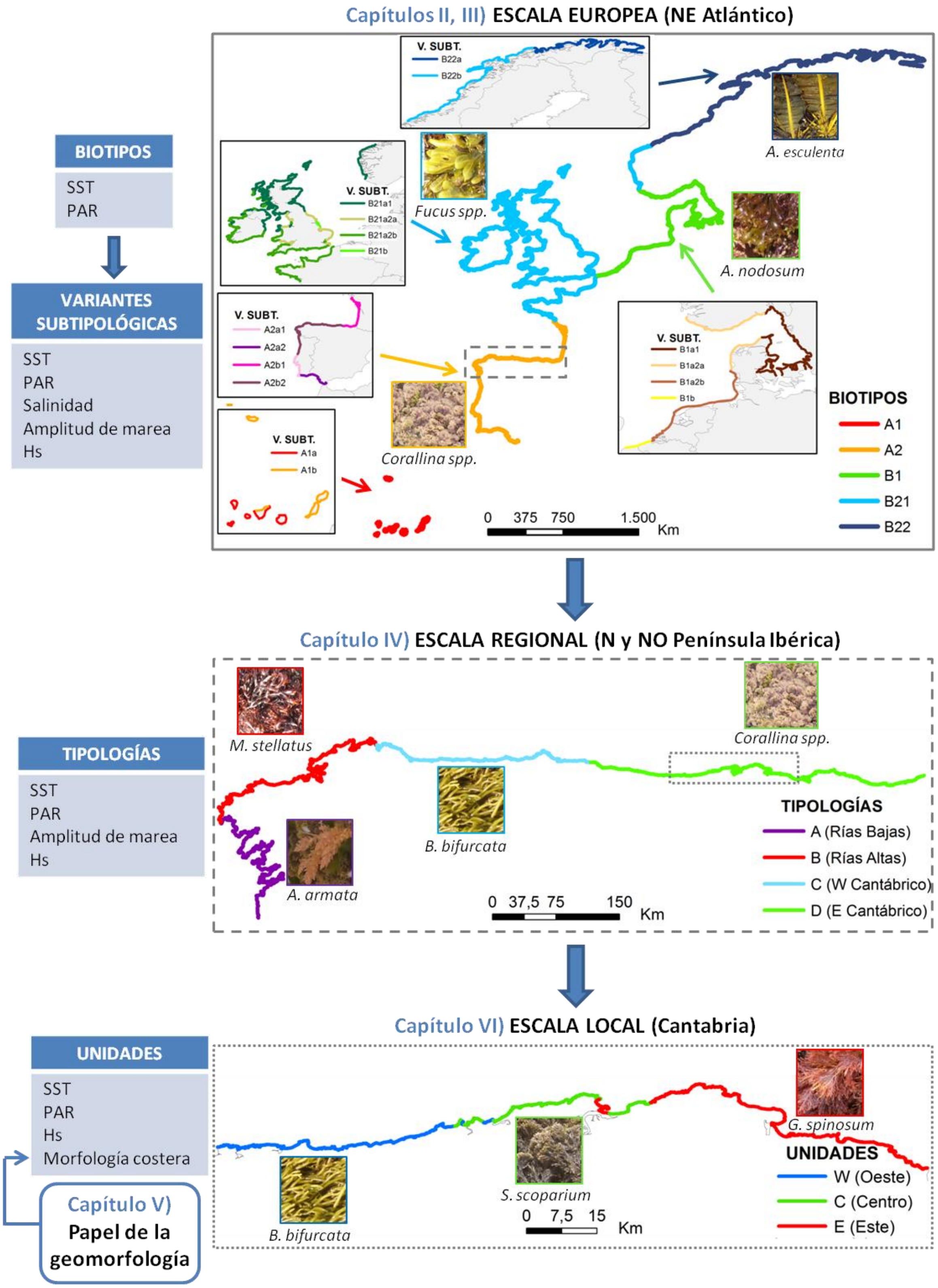


Figura 1. Resumen gráfico de los estudios llevados a cabo (clasificaciones ecológicas a diferentes escalas).

2. Capítulo II: Clasificación física a escala Europea

En este apartado se incluye una versión editada del artículo de investigación publicado en la revista Estuarine, Coastal and Shelf Science, vol. 112, pp. 105-114, por Ramos, E., Juanes, J.A., Galván, C., Neto, J.M., Melo, R., Pedersen, A., Scanlan, C., Wilkes, R., van den Bergh, E., Blomqvist, M., Kroup, H.P., Heiberg, W., Reitsma, J.M., Ximenes, M.C., Silió, A., Méndez F.J., González, B., en 2012 con el título "Coastal waters classification based on physical attributes along the NE Atlantic region. An approach for rocky macroalge potential distribution".

Para dar cumplimiento a la Directiva Marco del Agua (DMA; 2000/60/EC), es necesario evaluar los elementos de calidad biológica, entre los que se encuentra la vegetación. En el caso de la región del Nordeste Atlántico (NEA), se trata de una zona muy heterogénea, con aguas costeras que presentan una vegetación muy diversa, desde las Islas Canarias hasta Noruega. Por lo tanto, es fundamental el establecimiento de tipologías que ayuden a reducir la alta variabilidad biogeográfica y permitan comparar los diferentes métodos de evaluación aplicados en la región.

El principal objetivo de este capítulo es proporcionar la información adecuada para justificar el establecimiento de zonas costeras físicamente homogéneas, relacionadas con la distribución potencial de macroalgas a lo largo de la costa del NEA. Para establecer dicha clasificación cuantitativa se utilizarán características físico-químicas, incluyendo dos fases, la primera en la que se establecen los "biotipos" (grandes áreas), y la segunda en la que se analiza la variabilidad dentro de cada uno de los biotipos ("variantes subtipológicas").

Como primer paso para llevar a cabo la clasificación, la línea de costa del NEA se subdividió en 550 tramos consecutivos de 40 km de largo. A continuación, las variables físico-químicas temperatura superficial del agua (SST, por sus siglas en inglés) media, máxima, mínima y desviación estándar; radiación fotosintéticamente activa (PAR, por sus siglas en inglés) media, máxima y mínima; exposición al oleaje; amplitud de la marea; y salinidad se calcularon en los puntos de referencia de cada tramo, situados frente a la costa, a una distancia de 5 km. Esta información se obtuvo a partir de datos de satélite, excepto en el caso de la salinidad, obtenida a partir de una base de datos global de medidas *in situ* (World Ocean Database, WOD), utilizando los procedimientos específicos que se proponen en este trabajo (Tabla 1). En la Figura 2 se puede observar una representación de los valores medios de cada una de estas variables.

Tabla 1. Fuentes y características de las series de datos de cada una de las variables seleccionadas.

Variables	Fuente	Series de datos		
		Periodo	Resolución temporal	Resolución espacial
SST	Proyecto AVHRR Pathfinder v.5.0.	1981-2009	Media mensual	4 km
PAR	Sensor SeaWiFS	1997-2009	Media mensual	9.28 km
Altura de ola	Misiones TOPEX, TOPEX 2, Jason, Envisat, y GFO	1992-2009	Media mensual	1° x 1.5°
Amplitud de marea	Misión TOPEX/Poseidon	2007-2008	Minuto	7 km
Salinidad	NODC (NOAA)	1900-2010	*	*

* Distribución de datos aleatoria

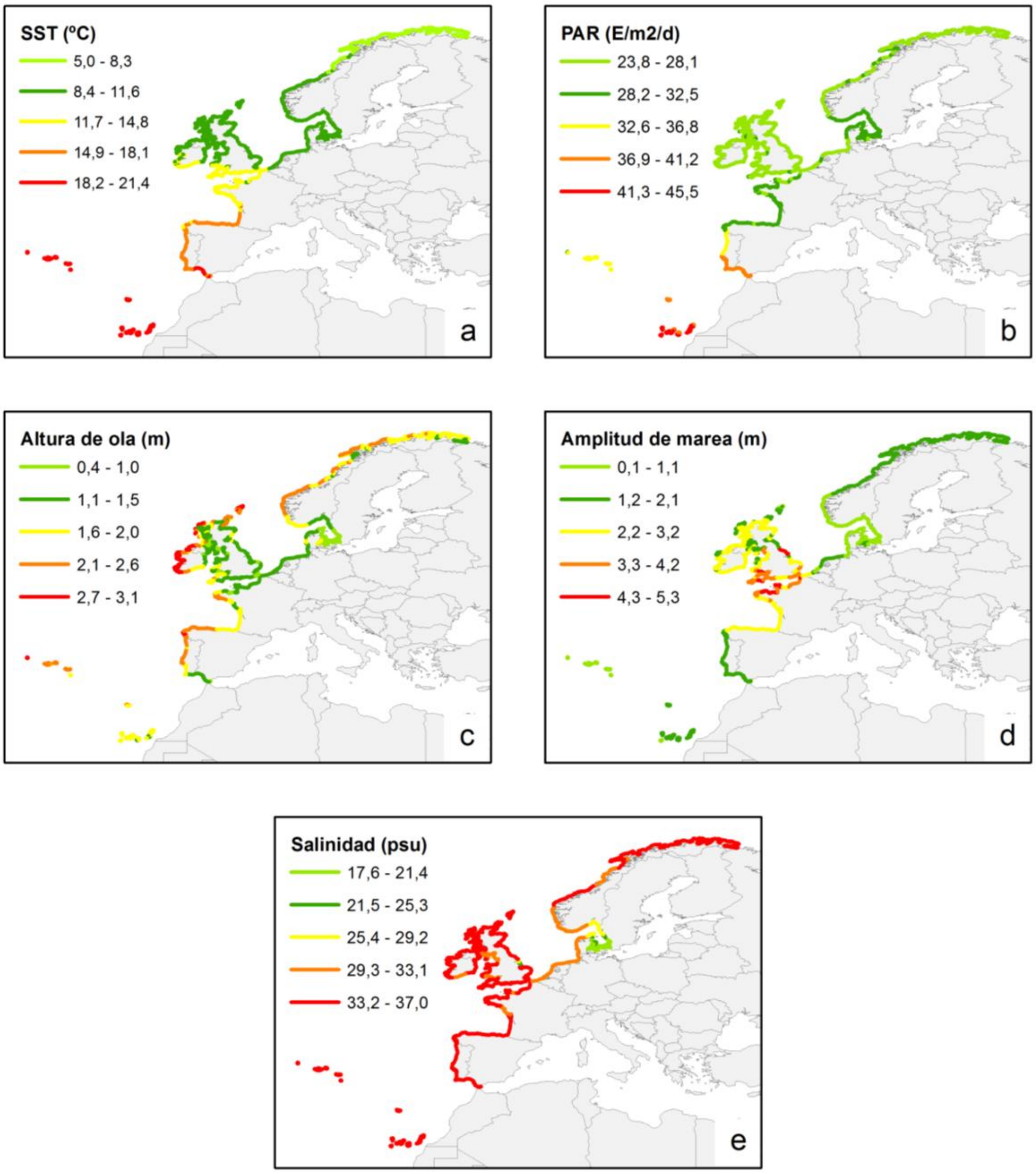


Figura 2. Distribución espacial de los valores medios de las variables físicas calculadas a lo largo de la región del NEA. Visualización de los datos utilizando cinco intervalos.

La primera división de las aguas costeras fue obtenida mediante un análisis jerárquico cluster, en el que se combinaron las variables físicas que determinan en mayor medida la distribución de especies a escala global (SST y PAR). De este modo, se establecieron cinco biotipos tomando como nivel de corte una distancia euclídea de 4.64 (Figura 3). Dichos grupos, reconocidos por expertos nacionales, han sido utilizados como información de referencia para la intercalibración de los métodos de evaluación de la vegetación dentro de la DMA.

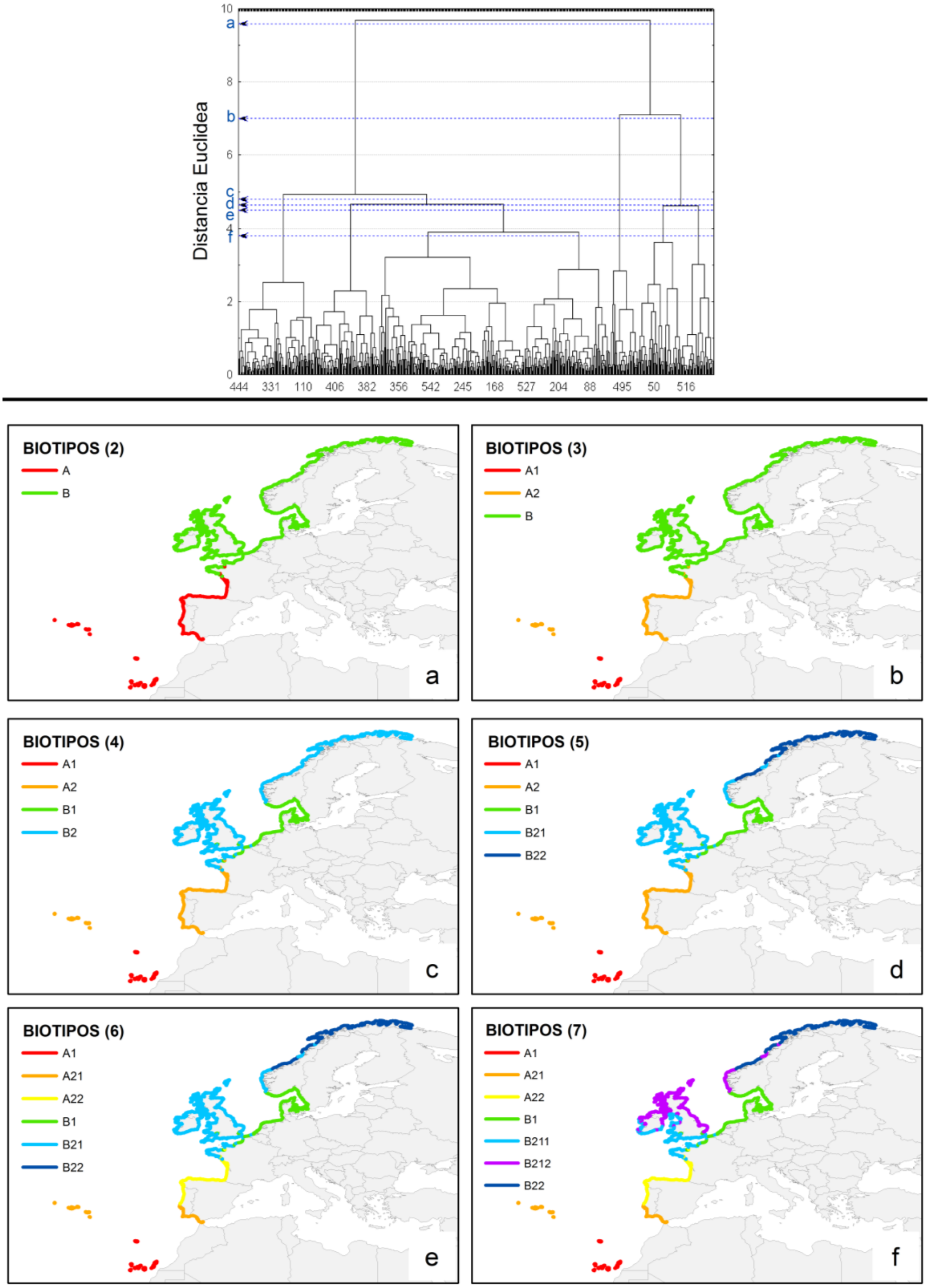


Figura 3. Resultados del análisis cluster basados en la caracterización física de los tramos costeros a lo largo de la región del NEA (umbrales referidos a las distancias Euclídeas de corte usados para la segregación de grupos de las figuras a-f). Abajo: grupos obtenidos a lo largo de la región del NEA para los distintos umbrales estadísticos: (a) 9.6 (2 biotipos), (b) 7 (3 biotipos), (c) 4.8 (4 biotipos), (d) 4.64 (5 biotipos), (e) 4.5 (6 biotipos) y (f) 3.8 (7 biotipos).

La variabilidad de las condiciones ambientales dentro de cada biotipo se analizó mediante un análisis cluster en el que se incluyeron, además de las dos variables anteriores, salinidad, amplitud de marea y altura de ola significante (Figura 4). Los resultados se compararon con clasificaciones previas llevadas a cabo a escala nacional, mostrando una concordancia media mayor del 70% en todos los países.

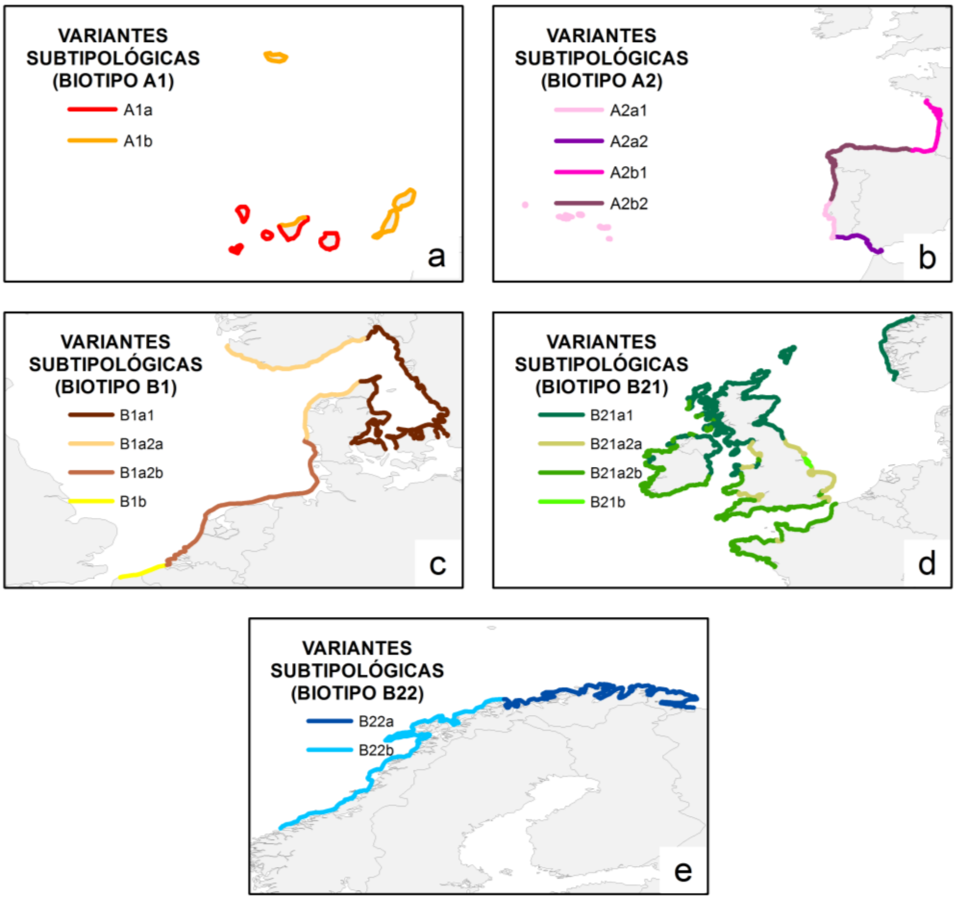


Figura 4. Resultados del análisis cluster para la segunda clasificación física. Desde arriba a la izquierda: (a) biotipo A1 (dos variantes subtipológicas), (b) biotipo A2 (cuatro variantes subtipológicas), (c) biotipo B1 (cuatro variantes subtipológicas), (d) biotipo B21 (cuatro variantes subtipológicas) y (e) biotipo B22 (dos variantes subtipológicas).

Los resultados presentados en este capítulo demuestran la idoneidad de la metodología aplicada para definir los posibles biotipos, así como la variabilidad dentro de estos a lo largo de la región del NEA, a partir de datos disponibles, homogéneos y estandarizados. Esta metodología permite eliminar la ambigüedad presente en el uso de clasificaciones subjetivas, asegurando que los resultados sean fiables y proporcionen una base sólida para determinar estadísticamente las diferencias entre biotipos. Además, la cuantificación de las variables mediante satélite supone una aproximación útil con un amplio futuro en estudios a escala global. De acuerdo a Roff y Taylor (2000), se puede asumir que la clasificación propuesta es capaz de representar la distribución de especies marinas, aunque su uso para la tipificación ecológica requiere una validación que confirme su significado biológico. Para ello, es necesario conocer la distribución actual de las comunidades de macroalgas a lo largo de esta extensa región y compararla con los grupos obtenidos en la clasificación física, es decir, validar su significado ecológico. Dicha validación constituye un punto clave, dado que permitiría predecir y delimitar los hábitats potenciales de especies y comunidades marinas.

3. Capítulo III: Clasificación biológica a escala Europea

En este apartado se incluye una versión editada del artículo de investigación publicado en la revista Estuarine, Coastal and Shelf Science, vol. 147, pp. 103-112, por Ramos, E., Puente, A., Juanes, J.A., Neto, J.M., Pedersen, A., Bartsch, I. Scanlan, C., Wilkes, R., van den Bergh, E., Ar Gall, E., Melo, R. en 2014 con el título "Biological validation of physical coastal waters classification along the NE Atlantic region based on rocky macroalgae distribution".

La metodología para clasificar la costa rocosa a lo largo del NE Atlántico basada en datos abióticos, desarrollada en el capítulo anterior (Ramos et al., 2012), requiere una validación biológica, con el fin de respaldar el significado ecológico de las tipologías físicas. De este modo, se obtendría un sistema de clasificación con base ecológica útil para la evaluación ambiental de los ecosistemas costeros, así como para la implementación de diferentes medidas legislativas. Por lo tanto, el principal objetivo de este capítulo es validar biológicamente la clasificación física obtenida anteriormente. Además, se proporciona información homogénea y estandarizada sobre la distribución biogeográfica de especies de macroalgas intermareales a lo largo del NE Atlántico y se caracterizan los biotipos físicos de acuerdo con datos de macroalgas.

En primer lugar, se generó una base de datos de especies de macroalgas intermareales en 117 estaciones distribuidas en la zona costera entre Noruega y la Península Ibérica.

Para ello, expertos de cada país aportaron datos semicuantitativos de abundancia de los taxones de macroalgas más representativos en tres niveles: común, raro o ausente, obteniéndose información sobre 117 taxones. Para evaluar la concordancia entre las comunidades de macroalgas y la clasificación física se llevaron a cabo análisis multivariantes de ordenación y clasificación (Figuras 5 y 6). Los resultados de dichos análisis revelan un claro gradiente latitudinal en la distribución de especies, debido principalmente a los órdenes Fucales y Laminariales, algas pardas que dominan la zona norte del NEA. Así, aunque es difícil establecer límites en un medio natural, parece claro que existe una zona de transición biogeográfica alrededor de Bretaña (Francia), que separa el área norte y sur del NE Atlántico (van den Hoek, 1975; Dinter, 2001). Además, dentro de la zona norte se encuentra otro límite pronunciado, que diferencia entre el norte de Francia, Reino Unido e Irlanda y el resto de la costa.

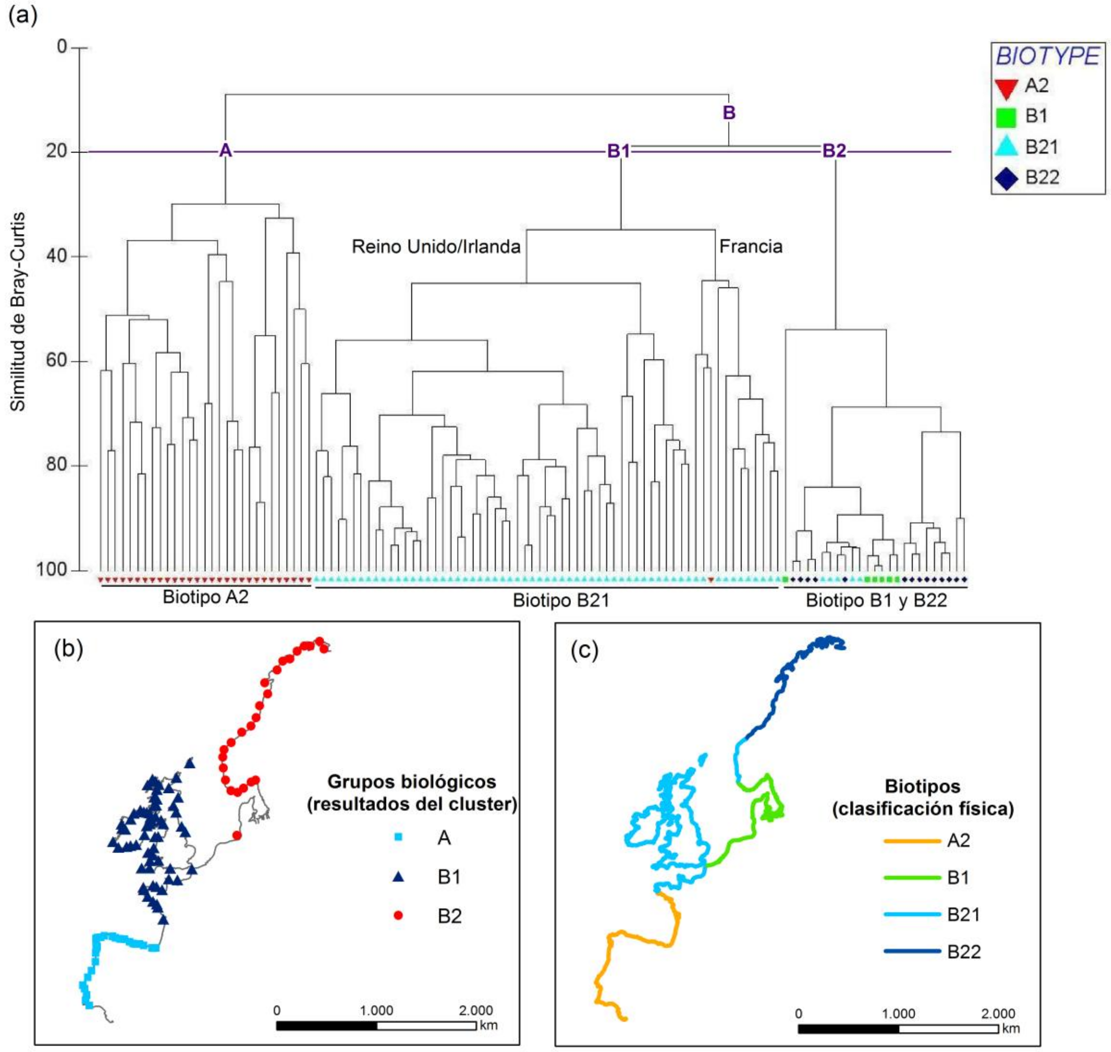


Figura 5. (a) Dendrograma resultado de la clasificación basada en datos de taxones de macroalgas, incluyendo la representación de los biotipos físicos (A2, B1, B21 y B22). (b) Representación de los grupos biológicos a lo largo de la región del NEA (corte a una distancia de similaridad de Bray-Curtis de 20). (c) Representación de los biotipos obtenidos en la clasificación física. Fuente: Ramos et al. (2012).

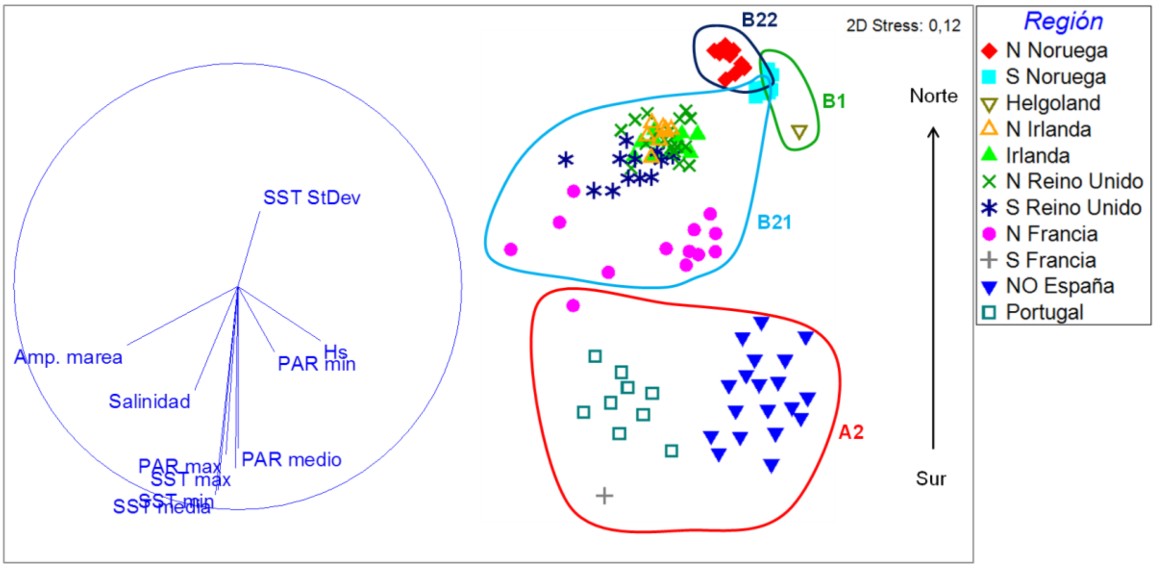


Figura 6. Análisis MDS de la distribución de los diferentes sitios de acuerdo a regiones geográficas. Los vectores definen correlaciones entre las macroalgas y las variables físicas: temperatura superficial del mar media anual (SST media), máxima (SST max), mínima (SST min) y desviación estándar (SST StDev); radiación fotosintéticamente activa media anual (PAR medio), máxima (PAR max) y mínima (PAR min); amplitud de marea media anual (Amp. marea); altura de ola significante (Hs); y salinidad.

En conclusión, los datos biológicos analizados en este estudio muestran la relevancia ecológica de la clasificación física previamente establecida a lo largo de la región del NEA. La distribución de macroalgas intermareales muestra gradientes latitudinales y longitudinales relacionados con factores físicos, siendo el gradiente latitudinal, asociado a la temperatura superficial del agua, el más importante. Por lo tanto, la clasificación ecológica establecida constituye una herramienta objetiva que facilita la gestión y conservación marina.

4. Capítulo IV: Clasificación de la costa a escala regional

En este apartado se incluye una versión editada del artículo de investigación in press en la revista Marine Ecology, por Ramos, E., Puente, A., Juanes, J.A., con el título "An ecological classification of rocky shores at a regional scale: a predictive tool for management of conservation values".

Tal y como se deduce en la exposición de motivos, las clasificaciones ecológicas del medio marino están emergiendo como una útil herramienta de predicción para la evaluación y conservación del medio marino. En este sentido, el desarrollo de un procedimiento jerárquico, capaz de analizar la variabilidad de las condiciones ambientales en diferentes zonas costeras y a diferentes escalas sería de gran interés. Por lo tanto, siguiendo el enfoque de la clasificación establecida a lo largo de la costa del NE Atlántico en los dos capítulos anteriores (Ramos et al., 2012; Ramos et al., 2014), sería conveniente llevar a cabo un análisis de la distribución de las variables abióticas y bióticas a una escala más reducida. Dichos análisis permitirían analizar en mayor detalle la variabilidad en ciertos ecotonos, como los límites de distribución conocidos para ciertas especies representativas.

Por lo tanto, el objetivo de este capítulo es desarrollar y validar una metodología de clasificación de las aguas costeras a escala regional, utilizando el procedimiento establecido a lo largo de la costa del NE Atlántico por Ramos et al. (2012; 2014). Este objetivo general se implementa a través de i) el desarrollo de una clasificación de la costa basada en variables físicas, asociadas a la distribución de las comunidades intermareales en el Cantábrico y ii) la validación de la idoneidad ecológica de dicha clasificación con datos biológicos homogéneos (la distribución actual de las especies de macroalgas intermareales).

Este estudio se ha llevado a cabo en el litoral N y NO de la Península Ibérica, entre las fronteras con Portugal y Francia. Con el objetivo de aplicar un procedimiento uniforme, se han establecido segmentos de la costa de igual longitud siguiendo la metodología establecida por Ramos et al. (2012), adaptada a esta escala regional. Así, a lo largo de una línea definida a 150 m de profundidad se obtuvieron 41 segmentos de 20 km de longitud, que posteriormente se proyectaron a la línea de costa. Esta profundidad permite obtener información fiable procedente de satélite y, a su vez, los datos pueden ser asociados a la variabilidad de las condiciones ambientales en la zona intermareal.

Las variables físicas (temperatura superficial del agua máxima y mínima; exposición al oleaje media; amplitud de marea media; y radiación fotosintéticamente activa media y mínima) se han seleccionado de acuerdo a su papel ecológico, disponibilidad y criterios estadísticos. Las series de datos se han obtenido a partir de sensores en satélites, excepto la altura de ola significante, que se obtuvo a partir de modelado numérico

(GOW, Reguero et al., 2012) (Tabla 2). En la Figura 7 se puede ver la representación espacial de cada una de estas variables.

Tabla 2. Fuentes y características de las series de datos de cada una de las variables seleccionadas.

Variables	Source	Series de datos		
		Periodo	Resolución temporal	Resolución espacial
SST	Proyecto AVHRR Pathfinder v.5.0.	1981-2008	Media mensual	4 km
PAR	Sensor SeaWIFS	1997-2009	Media mensual	9.28 km
Amplitud de marea	Misión TOPEX/Poseidon	2007-2008	Minuto	7 km
Altura de ola	Reanálisis GOW (modelo WaveWatch III)	1992-2009	Media mensual	0.1°

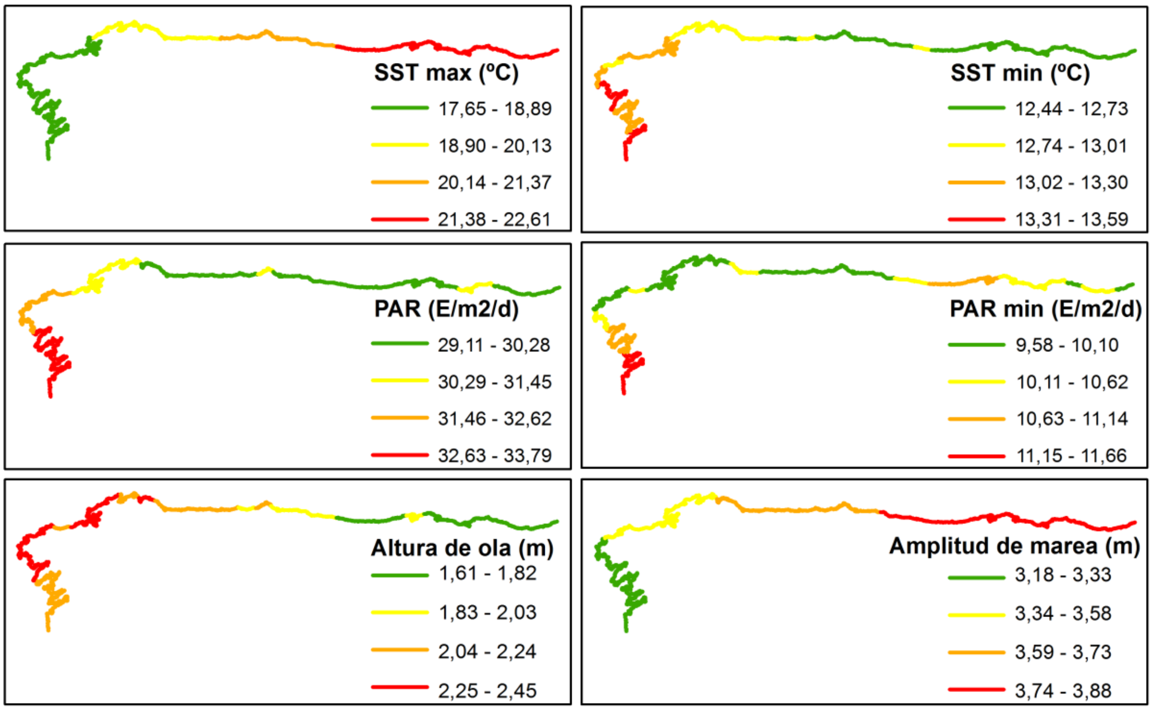


Figura 7. Distribución espacial de las variables usadas en la clasificación física a lo largo de la región N y NO de la Península Ibérica. Visualización de los datos utilizando cuatro intervalos.

Los segmentos de costa se clasificaron de acuerdo a las variables físicas combinando dos técnicas: 1) redes neuronales (Self-Organizing Map, SOM) y 2) el algoritmo k-medias. Como resultado de la clasificación física se obtuvieron cuatro tipologías: Rías Bajas, Rías Altas, Cantábrico Oeste y Cantábrico Este, cuyos límites se representan en la Figura 8.

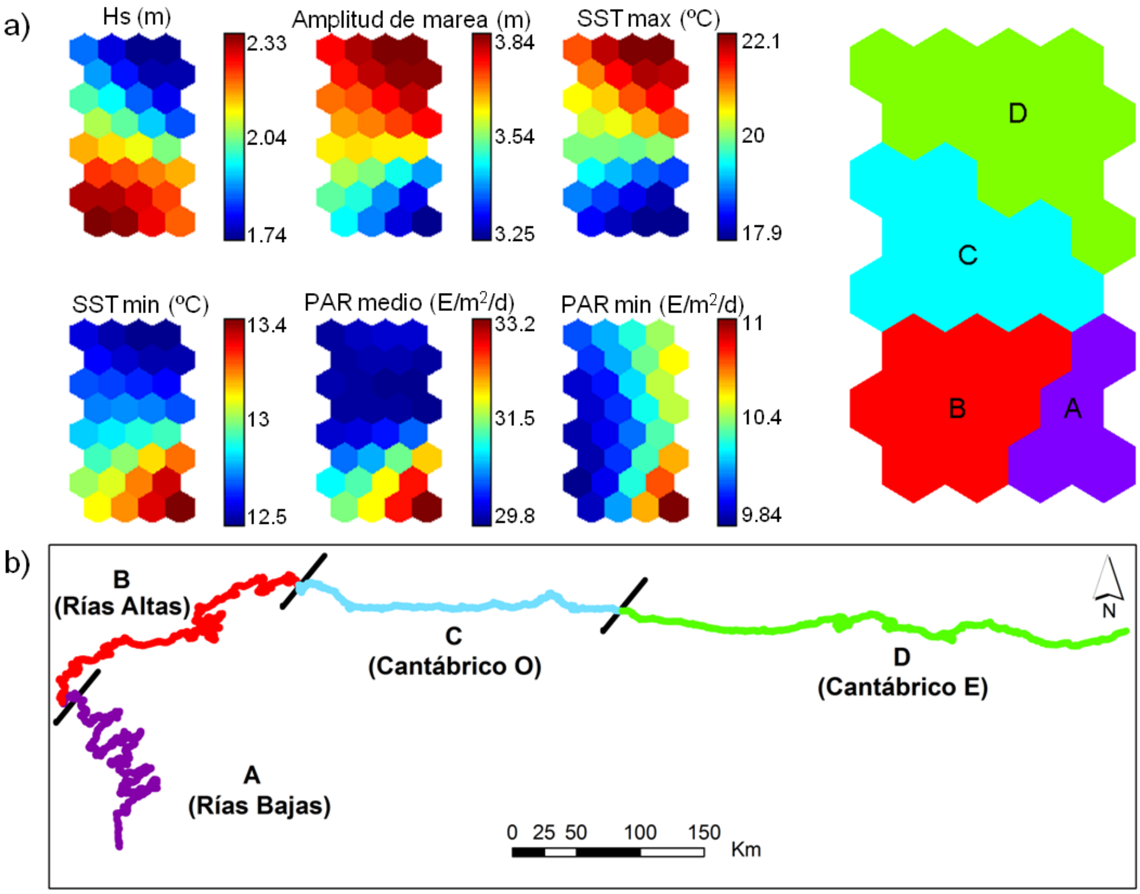


Figura 8. (a) A la izquierda, gradiente de cada una de las variables físicas incluidas en el análisis SOM. A la derecha, resultados del k-medias en el mapa de la SOM. (b) Mapa de las tipologías obtenidas en la clasificación física.

Para validar la clasificación con datos biológicos, se tomaron muestras de forma simultánea y homogénea en 21 sitios, tratando de representar toda la variabilidad física del área de estudio. De acuerdo a un procedimiento estratificado, se establecieron diez cuadrículas de 50x50 cm en 2-3 transectos por sitio. Las especies de macroalgas intermareales fueron identificadas *in situ* y la cobertura de cada una de ellas se obtuvo mediante análisis fotográfico. Los análisis estadísticos llevados a cabo para comprobar el ajuste entre la distribución de macroalgas y las tipologías físicas confirman la importancia ecológica de estas en los niveles de marea donde las algas son el elemento estructural, es decir, el intermareal medio e inferior (Figura 9). De acuerdo con los datos biológicos, las mayores diferencias se encontraron entre las Rías Altas y el resto de la costa N y NO de la Península Ibérica. Los resultados obtenidos reflejan el patrón general descrito por otros autores en el último siglo (Fischer-Piette, 1963; Anadón y Niell, 1981; Díez et al., 2003; Gorostiaga et al., 2004), así como los recientes cambios observados en el área de estudio (Fernández, 2011; Duarte et al., 2013). Así, las especies de la tipología Rías Altas son similares a las del norte de Europa, debido a las condiciones ambientales de mayor altura de ola y menor temperatura. Por el contrario, la tipología Cantábrico E presenta macroalgas características de zonas meridionales, con poca presencia o ausencia de Ochrophyta (como *Fucus* spp., *Himanthalia elongata*, *Laminaria* spp., *Saccorhiza polyschides*) y otras especies de aguas frías (*Chondrus crispus, Mastocarpus stellatus*).

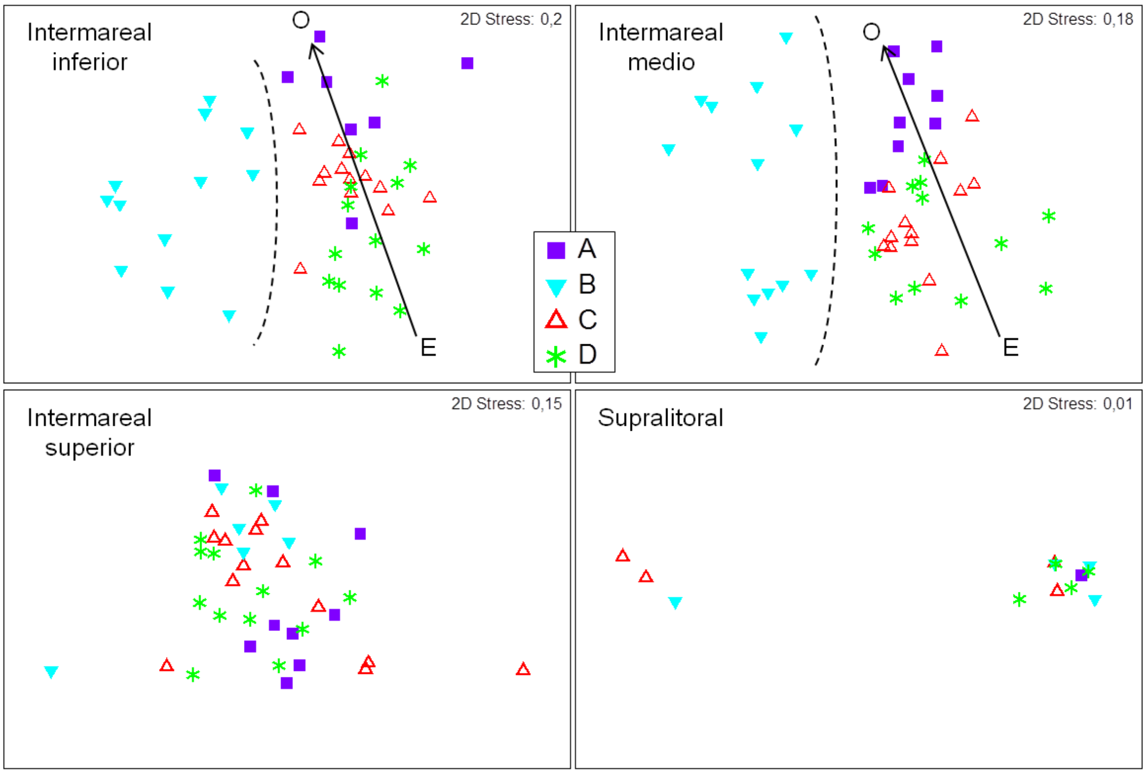


Figura 9. Análisis MDS basado en la distribución de macroalgas en cada nivel del intermareal. Los transectos han sido representados de acuerdo a las tipologías físicas.

En conclusión, este estudio presenta una metodología aplicable a escala regional que permite identificar de forma precisa la variabilidad espacial de las condiciones ambientales y los gradientes en la distribución de las macroalgas intermareales más características. Se muestra, por lo tanto, la idoneidad de adaptar las metodologías de clasificación a los requerimientos de las diferentes escalas, como herramienta de gestión aplicable al establecimiento de criterios de evaluación y diagnóstico del estado de conservación de los ecosistemas costeros.

5. Capítulo V: El papel de la geomorfología en la distribución de macroalgas a escala local

En este apartado se incluye una versión editada del artículo de investigación enviado a revisión a la revista Estuarine, Coastal and Shelf Science, por Ramos, E., Díaz de Terán, J.R., Puente, A., Juanes, J.A., con el título "The role of geomorphology in the distribution of intertidal rocky macroalgae in the NE Atlantic region".

Es ampliamente conocido que la distribución de macroalgas en sustrato rocoso depende de diversos factores abióticos. A su vez, diferentes trabajos han puesto de manifiesto el importante papel que juega la geomorfología a la hora de explicar los patrones de distribución de comunidades bentónicas de fondo rocoso a escala local (e.g., Cerrano et al., 1999; Bavestrello et al., 2000). Sin embargo, la influencia de las características geomorfológicas en las comunidades de macroalgas ha recibido, en general, poca atención. Por ello, el objetivo de este estudio es analizar la influencia de la geomorfología en la distribución y estructura de las comunidades de macroalgas intermareales en sustrato rocoso. De forma más específica, se busca identificar cuáles son los factores geomorfológicos más determinantes en los patrones de distribución de las comunidades de macroalgas, contribuyendo de este modo al conocimiento de la ecología de dichas comunidades y de las especies que las integran.

El estudio se ha llevado a cabo en la costa de Cantabria (Norte de España), donde se han analizado trece sitios con el fin de obtener las coberturas de las distintas especies de macroalgas (Figura 10), siguiendo la metodología establecida por Ramos et al. (in press) en el intermareal medio e inferior. En estos sitios se han analizado, a su vez, las siguientes características geomorfológicas: procesos activos, morfología costera, orientación de la costa y litología (Figura 11). Dichas características han sido obtenidas principalmente mediante análisis de Mapas Geológicos.

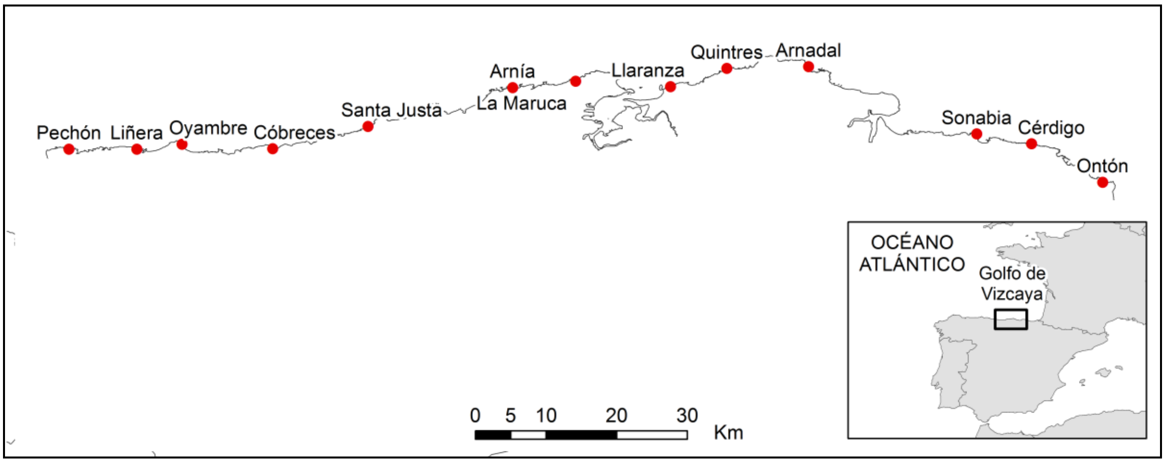
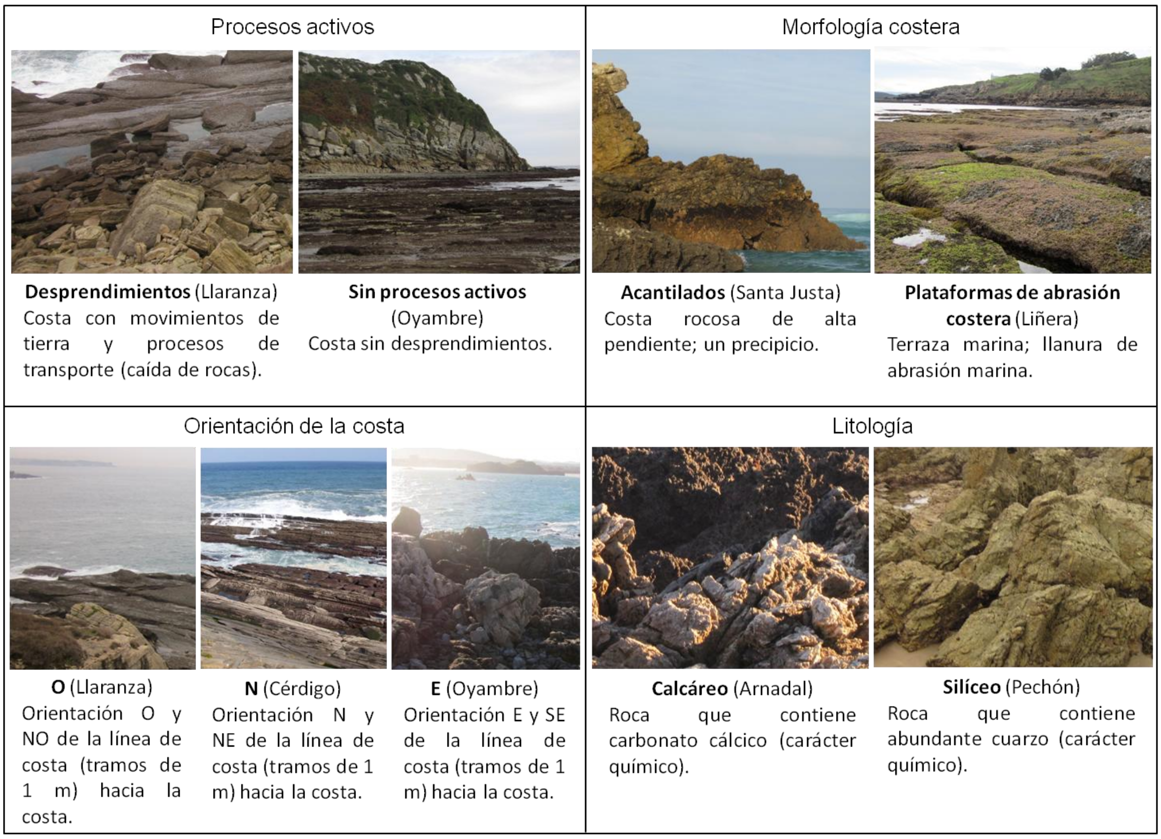


Figura 10. Localización de los 13 sitios de muestreo a lo largo de la costa de Cantabria (Golfo de Vizcaya).


Procesos activos

Desprendimientos (Llaranza)
Costa con movimientos de tierra y procesos de transporte (caída de rocas).

Sin procesos activos (Oyambre)
Costa sin desprendimientos.

Morfología costera

Acantilados (Santa Justa)
Costa rocosa de alta pendiente; un precipicio.

Plataformas de abrasión costera (Liñera)
Terraza marina; llanura de abrasión marina.

Orientación de la costa

O (Llaranza)
Orientación O y NO de la línea de costa (tramos de 1 m) hacia la costa.

N (Cérdigo)
Orientación N y NE de la línea de costa (tramos de 1 m) hacia la costa.

E (Oyambre)
Orientación E y SE de la línea de costa (tramos de 1 m) hacia la costa.

Litología

Calcáreo (Arnadal)
Roca que contiene carbonato cálcico (carácter químico).

Silíceo (Pechón)
Roca que contiene abundante cuarzo (carácter químico).

Figura 11. Ejemplos y descripción de las categorías de las variables geomorfológicas.

Para analizar la relación entre las macroalgas y la geomorfología se han aplicado distintos análisis multivariantes. Los resultados relativos a los índices de diversidad muestran diferencias significativas para la morfología y orientación de la costa en el intermareal medio y para la litología en el intermareal inferior. En cuanto a la composición de la comunidad, esta presenta diferencias de acuerdo a la morfología y a la orientación de la costa.

También se ha realizado un análisis de regresión logística, prediciendo la probabilidad de ocurrencia de las especies de macroalgas como respuesta al predictor variables geomorfológicas. Las diferencias más significativas en cuanto a preferencia por el sustrato se encontraron entre *Bifurcaria bifurcata*, que aparece en plataformas de abrasión orientadas hacia el este, y *Corallina officinalis/Ellisolandia elongata* y *Gelidium spinosum*, que se encuentran en acantilados orientados hacia el norte y el oeste en el intermareal inferior (Figura 12).

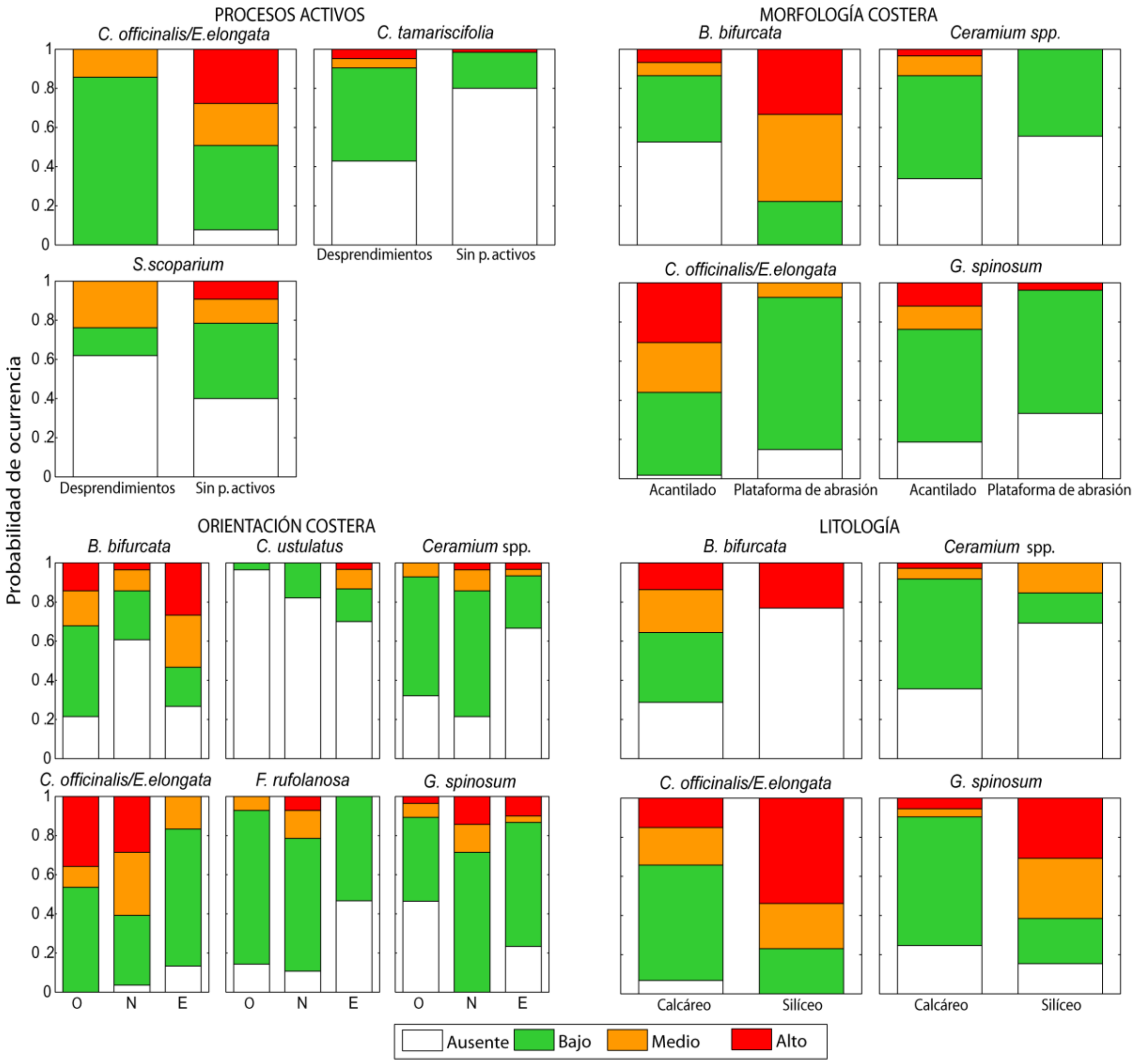


Figura 12. Probabilidad de ocurrencia de cada especie condicionada a las variables geomorfológicas en el intermareal inferior. Sin p. activos: Sin procesos activos.

De acuerdo a los resultados obtenidos, la distribución de macroalgas intermareales está parcialmente relacionada con las características geomorfológicas a escala local. Esta influencia tiene lugar de diferente modo y con distinta intensidad, dependiendo de la franja intermareal y del nivel de organización biológico analizado. Por lo tanto, puede concluirse que las variables geomorfológicas ayudan a caracterizar la distribución de las especies, aunque su valor predictivo es limitado, posiblemente debido a la interacción con otros factores ambientales que influyen en la distribución de macroalgas y a que su relación no es siempre directa.

6. Capítulo VI: Clasificación de la costa a escala local

Continuando con la aproximación jerárquica previamente mencionada, la protección de las áreas costeras tiene lugar a diferentes escalas espaciales, desde zonas extensas hasta las más reducidas, siendo estas últimas donde se realizan importantes planes de conservación a través de actividades de gestión específicas. Una clasificación ecológica a gran escala es una herramienta de gran utilidad para el establecimiento de planes de conservación y la implementación de programas efectivos en una región en particular. El objetivo de este capítulo es, por lo tanto, establecer una metodología de clasificación de las aguas costeras a escala local basada en variables físicas y verificar su idoneidad de acuerdo a la distribución de las comunidades de macroalgas intermareales. La metodología aplicada seguirá las aproximaciones desarrolladas a escala europea (Ramos et al., 2012; Ramos et al., 2014) y regional (Ramos et al., in press) en capítulos anteriores.

Este estudio se ha llevado a cabo en la costa de Cantabria (Norte de la Península Ibérica). En primer lugar, la línea de costa se ha dividido en tramos de 1 km, donde se han calculado los indicadores de las variables abióticas temperatura superficial del agua, radiación fotosintéticamente activa, altura de ola significante y morfología costera. Tanto temperatura como radiación se han obtenido a partir de sensores satelitales; la altura de ola mediante reanálisis numérico (DOW, Camus et al., 2013); y la morfología costera mediante análisis de Mapas Geológicos y trabajo de campo (Ramos et al., submitted) (Tabla 3). En la Figura 13 se puede observar la variación de estas variables a lo largo de la costa.

Tabla 3. Fuentes y características de las series de datos de cada una de las variables seleccionadas.

Variables	Fuente	Series de datos		
		Periodo	Resolución temporal	Resolución espacial
SST	GHRSST (sensor)	2005-2008	Media diaria	0.02°
PAR	MyOcean (sensores SeaWifs y Modis Aqua)	1997-2010	Media mensual	2 km
Altura de ola	Reanálisis DOW	1948-2008	Media mensual	200 m
Morfología costera	Mapas geológicos (IGME) y trabajo de campo	-	-	1 km

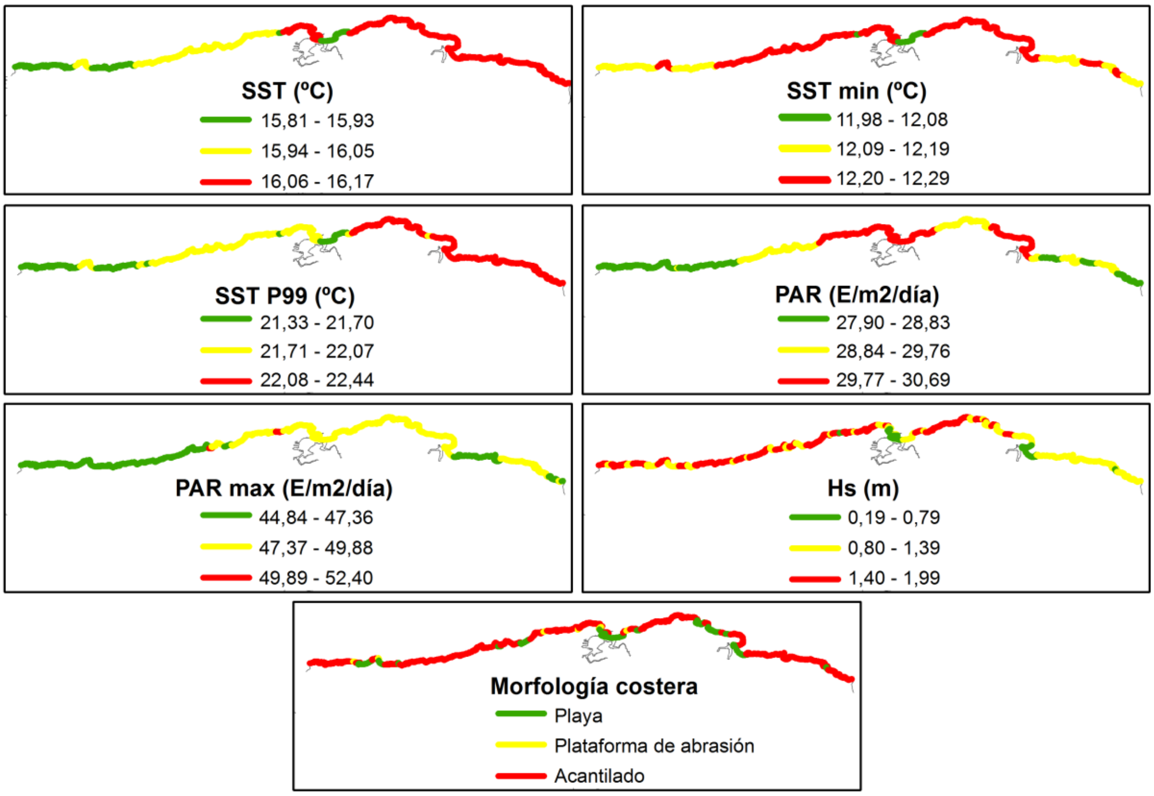


Figura 13. Distribución espacial de las variables usadas en la clasificación física a lo largo de la costa de Cantabria. Visualización de los datos utilizando tres intervalos.

Para llevar a cabo la clasificación física, se ha aplicado un sistema jerárquico con i) un primer nivel en el que las variables cuantitativas (SST media, mínima y percentil 99; PAR medio y máximo y altura de ola media) se utilizan para realizar un análisis de redes neuronales SOM y un k-medias y ii) un segundo nivel en el que se subdividen los grupos previamente obtenidos de acuerdo a la variable cualitativa geomorfología costera. Como resultado se han obtenido tres grupos: costa Oeste, Centro y Este (Figura 14), que a su vez pueden subdividirse atendiendo a la geomorfología costera en acantilados o plataformas de abrasión.

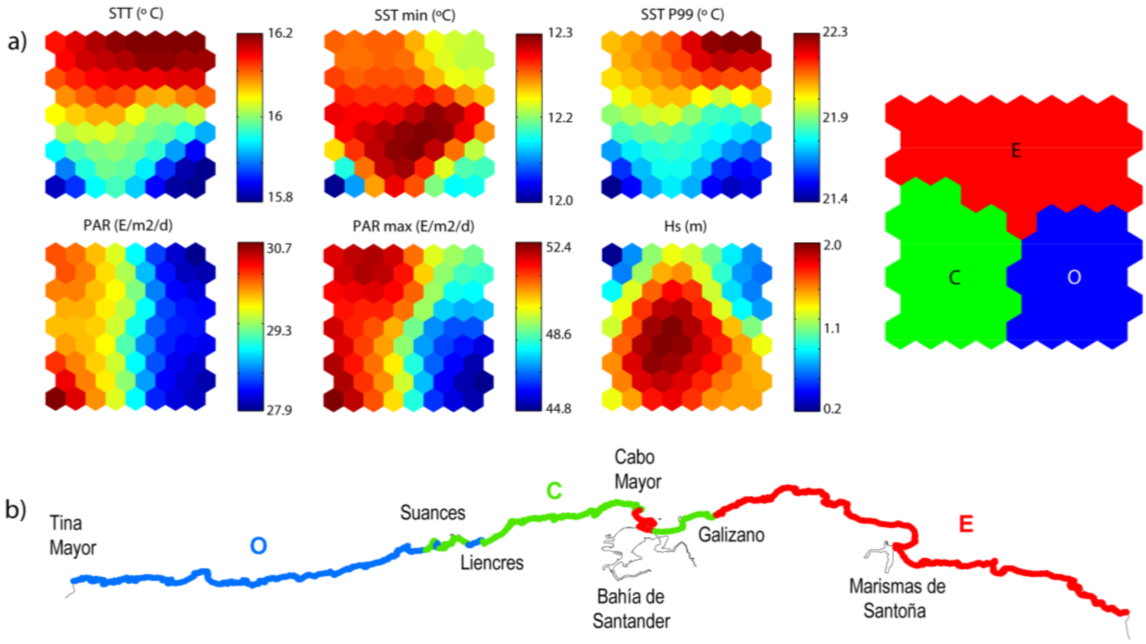


Figura 14. (a) A la izquierda, gradiente de cada una de las variables físicas incluidas en el análisis SOM. A la derecha, resultados del k-medias en el mapa de la SOM. (b) Mapa de las unidades obtenidas en la clasificación física.

Para validar la clasificación con datos biológicos se han analizado 14 estaciones de la costa de Cantabria, siguiendo la metodología establecida por Ramos et al. (in press) en el intermareal medio e inferior. Los análisis estadísticos realizados muestran concordancia entre la clasificación física y la distribución de macroalgas (Figura 15). En el intermareal inferior, *Bifurcaria bifurcata* y *Stypocaulon scoparium* dominan las zonas oeste y centro, mientras que *Corallina officinalis/Ellisolandia elongata* y *Gelidium* spp. son los taxones más abundantes hacia el este. Sin embargo, a lo largo de toda la zona de estudio el intermareal medio está dominado por *C. officinalis/E. elongata*. Los patrones de distribución de especies observados a escala local son explicados en gran parte por la variable ambiental exposición al oleaje.

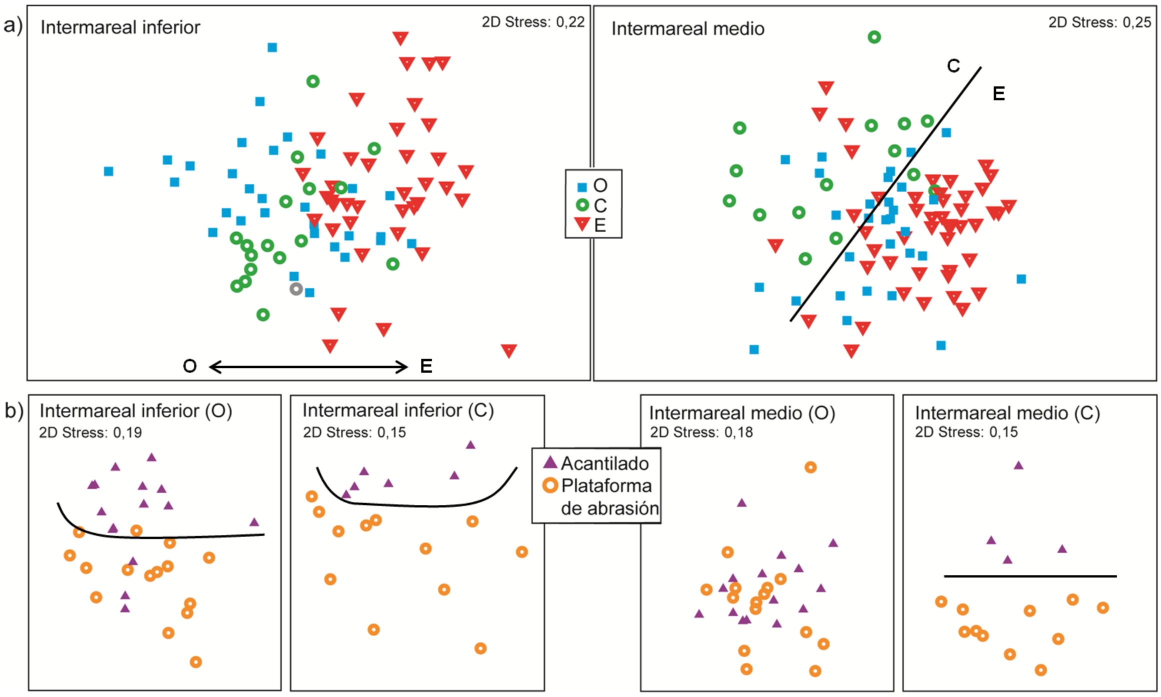


Figura 15. Análisis MDS basado en la distribución de macroalgas. (a) Cuadrículas representadas de acuerdo a las unidades geográficas (W, C o E) en cada nivel intermareal. (b) Cuadrículas representadas de acuerdo a la morfología costera (acantilado o plataforma de abrasión) en cada nivel intermareal y unidad geográfica.

En este capítulo se ha completado un sistema de clasificación de la costa a lo largo del NE Atlántico centrándose en la escala local (costa de Cantabria), mostrando de nuevo la necesidad de adecuar las metodologías (adquisición de datos, análisis estadísticos, etc.) a cada nivel de definición. La aproximación jerárquica establecida en este estudio divide la costa en tres unidades y cinco subunidades ambientales, proporcionando la posibilidad de adoptar el nivel de detalle más apropiado para cada caso de estudio. La metodología desarrollada podrá ser de utilidad en la gestión y protección frente a presiones antrópicas y cambio climático en los ecosistemas costeros.

7. Conclusiones generales y futuras líneas de investigación

7.1. Conclusiones generales

De acuerdo al objetivo general de esta tesis se ha llevado a cabo un sistema de clasificación de la costa rocosa intermareal a tres escalas: Europea (NE Atlántico), regional (N y NO de la Península Ibérica) y local (Cantabria). Los resultados obtenidos permiten inferir las siguientes conclusiones generales:

- La metodología desarrollada, en la que se realiza una clasificación basada en variables físicas, permite establecer un sistema de división de la costa que reconoce la variabilidad ambiental.

- El sistema de clasificación jerárquica permite utilizar el nivel de detalle y resolución más adecuados en cada caso, de acuerdo a la extensión del área de estudio, pudiendo ser aplicado, además, en distintas zonas costeras.

- Los principales grupos obtenidos a lo largo del NE Atlántico son los biotipos A1 (Islas Canarias y Madeira), A2 (Península Ibérica, Sur de Francia y Azores), B1 (costa continental del Mar del Norte, y la zona de Kattegat y Skagerrak hasta Rogaland en Noruega), B21 (Reino Unido e Irlanda) y B22 (Trøndelag y Norte de Noruega). La variabilidad de las condiciones ambientales dentro de estas grandes regiones biogeográficas se analiza a través de las variantes subtipológicas.

- En la costa N y NO de la Península Ibérica se han definido cuatro tipologías: Rías Bajas (A), Rías Altas (B), Cantábrico Oeste (C) y Cantábrico Este (D).

- La aproximación jerárquica adoptada para la costa de Cantabria divide esta en tres unidades (Oeste, Centro y Este) y cinco subunidades (Oeste-Acantilados, Oeste-Plataformas de abrasión, Centro-Acantilados, Centro-Plataformas de abrasión y Este).

- Aunque es difícil establecer límites en un sistema natural, los datos relativos a la distribución de especies de macroalgas intermareales confirman, en general, la idoneidad ecológica de las tipologías establecidas a las distintas escalas espaciales con base en variables abióticas.

- Las metodologías de reducción de escala desarrolladas a partir de la clasificación a escala europea han demostrado ser apropiadas, adaptándose al reconocimiento de la variabilidad de las condiciones ambientales y la distribución de especies y comunidades a escala regional y local.

- La cuantificación de variables a través de sensores en satélites y modelado numérico constituye una aproximación útil y de gran futuro al poder ser aplicada a distintas escalas de estudio, incluyendo la global, y en diferentes áreas geográficas.

- Las variables geomorfológicas muestran una relación con la distribución de macroalgas a escala local. Sin embargo, estas variables no parecen ser las más determinantes ya que, en la mayor parte de los casos son otros los factores que, en última instancia, determinan la distribución de especies en la zona intermareal.

- La aproximación metodológica propuesta ofrece una herramienta estadística objetiva para la definición de regiones ecológicas relevantes, que puede ser útil para la protección ambiental y la gestión de zonas marinas.

7.2. Futuras líneas de investigación

Los estudios llevados a cabo han revelado la existencia de ciertos aspectos mejorables en los procedimientos descritos para alcanzar los objetivos perseguidos, así como la posibilidad de explorar nuevos aspectos en el complejo campo de los sistemas de clasificación ecológica. A continuación, se mencionan los aspectos más relevantes de las posibles futuras líneas de investigación relacionadas con esta tesis.

- En cuanto a las variables físicas, se podría estudiar la incorporación de nuevos factores en el sistema de clasificación. Para llevar a cabo esta tarea será necesaria la interacción entre expertos de distintas disciplinas, como ecólogos, oceanógrafos y meteorólogos.

- Respecto a la clasificación a lo largo del NE Atlántico, el disponer de información más extensa y cuantitativa sobre la distribución de especies de macroalgas permitiría llevar a cabo una validación ecológica más precisa, así como una caracterización biológica detallada.

- En zonas singulares con características específicas, como la costa de Skagerrak y Kattegat, sería recomendable llevar a cabo análisis regionales o locales en detalle.

- La dominancia de especies de fauna en la zona alta del intermareal impide una validación adecuada con especies de macroalgas en este nivel. Por ello, podría incluirse el análisis de invertebrados bentónicos en el sistema de clasificación. Además, el análisis de macroalgas submareales podría proporcionar un valor ecológico más robusto a la clasificación.

- El desarrollo de un nivel adicional, a una escala de estudio aún más reducida, permitiría el análisis de las asociaciones de especies en mayor detalle, relacionando las comunidades con factores abióticos a microescala, tales como sombra, pendiente, rugosidad, sedimentación, presencia de pozas, etc.

- La incorporación del factor tiempo, estudiando las variaciones estacionales e interanuales, sería de gran utilidad. Así, se analizaría en detalle la progresión o regresión de especies a lo largo del tiempo y su posible relación con el cambio climático.

Summary

SUMMARY

The general objective of this thesis is to develop a methodology for the classification of intertidal rocky shores at European, regional and local scales, through the relation between abiotic characteristics and species distribution. Bearing this in mind, it was tried to provide suitable information to justify the establishment of physically homogeneous coastal zones for the potential distribution of intertidal macroalgae under the three study areas, taking into account the specific requirements of the different levels of definition.

First, a classification system of coastal wasters based on abiotic variables was developed along the North East Atlantic region. Physico-chemical factors (sea surface temperature, photosynthetically active radiation, salinity, tidal range and significant wave height) were calculated in consecutive points situated in a parallel line to the coast. Five biotypes were identified as broad geographic regions. Then, variability of environmental conditions inside these biotypes (subtypological variants) was also analyzed. This way, the feasibility of this methodological approach as a useful tool for the assessment of coastal systems at a European scale was tested.

A biological validation was required in order to support the ecological meaning of the physical typologies previously obtained. A semi-quantitative data base of intertidal macroalgae species occurring in the coastal area between Norway and the South Iberian Peninsula was generated. Ordination and classification multivariate analyses revealed a clear latitudinal gradient in the distribution of macroalgae species resulting in two distinct groups: one northern and one southern group, separated at the coast of Brittany (France). In general, the results based on biological data coincided with the results based on physical characteristics. The ecological meaning of the coastal waters classification at a broad region shown in this work demonstrates that it can be useful as a practical tool for conservation and management purposes.

Then, a downscaling methodology was required to develop a classification of coastal waters at a regional scale. The N and NW Spanish coastline was classified according to

physical variables (sea surface temperature, photosynthetically active radiation, tidal range and significant wave height) using techniques adapted to the study scale. To validate the classification with biological data, intertidal macroalgae were simultaneously and homogenously sampled. The physical classification identified four typologies: Lower Rias, Upper Rias, W Cantabric and E Cantabric. Statistical analyses confirmed the ecological significance of these typologies at the tidal levels where seaweeds are a structural element (lower and middle intertidal). Thus, the classification methodology has a potential application as a management tool.

At a local scale, it was first necessary to analyze the relation between geomorphological variables (active processes, coastal morphology, coastal orientation and lithology) and rocky intertidal macroalgae species. Information about both cover of macroalgae species and geomorphological features was obtained in several points along the coast of Cantabria. The study of their relation was carried out through multivariate analysis and logistic regression at three levels of organization: community descriptive parameters, assemblage composition and species preferences. Our results showed that coastal morphology and coastal orientation were the principal geomorphological factors explaining the structure of macroalgae communities. Thus, some of the geomorphological variables are among the environmental factors that determined the distribution of intertidal macroalgae communities at a local scale, although not always in a direct way.

Finally, an ecological classification at a local scale was developed, as a useful tool for conservation planning and for the implementation of effective programs in a particular region. The methodology previously established at broader areas was adapted to classify the coast of Cantabria (N Spain) using the variables sea surface temperature, photosynthetically active radiation, significant wave height and coastal morphology. The ecological groups were obtained through a hierarchical classification, a first level that encompass quantitative variables grouping according to SOM and k-means analyses and a second level that subdivides the previous groups according to the categorical variable coastal morphology. Thereby, three groups were obtained (W, C and E coast), subdivided in cliffs or wave-cut platforms. To validate the classification with biological data, covers of intertidal macroalgae species were homogenously obtained in 14 sites

and several statistical analyses were applied to test its ecological significance. A general agreement between macroalgae distribution and physical units was obtained. This classification complete a hierarchical framework to classify the NE Atlantic coast, a promising standard approach that allows to apply the most suitable resolution according to the study extension and that could be applicable to a wide range of coastal areas.

According to the general objective of this thesis, a rocky coast classification system has been established at three levels: European scale (NE Atlantic), regional scale (N and NW Iberian Peninsula) and local scale (Cantabria). The methodology is based on the analysis of the abiotic characteristics that determine the macroalgae species distribution. This way, physical data obtained by specific procedures (e.g., satellite data and numerical modelling) and examined by statistical analyses could be applied to obtain groups with ecological significance characterised by different communities and species distribution.

Chapter I

Introduction and background to the research

Chapter I. Introduction and background to the research

1.1. Motivations for the research

The coastal environment encompasses a broad array of ecosystems, ranging from coral reefs, mangroves, tidal wetlands, seagrass beds and swamps, to sandy beaches and rocky shores. Despite their significant value for the conservation and maintenance of biodiversity and provisioning of ecosystem services, coastal environments have been greatly impacted by human activities (Costanza et al., 1997), because coastal areas are at the centre of economic activities and harbour more than 60% of the world population (Hixon et al., 2001). According to the European Environment Agency (EEA, 2010), there is abundant evidence that the European coast is subject to degradation by various causes, such as destruction of habitats, eutrophication, pollution, erosion, invasive species or exploitation of resources. In addition, many of these impacts are exacerbated by climate change (e.g., Lozano et al., 2004; Philippart et al., 2011). Therefore, the management of coastal zones in the form of action plans is urgently needed to achieve preservation goals (Boesch, 2006).

The emergence of a worldwide environmental management arose in the 1990s, highlighting the need of integrating pollution control and developing a coordinate ecosystem approach which combines natural and social sciences (Apitz et al., 2006). Through several international conventions and organizations (e.g., the Earth Summits, the Convention of Biological Diversity, the United Nations Environment Programme) countries all over the world have reached an agreement to achieve environmental sustainability. Therefore, the management and conservation of coastal environments has become a complex multidisciplinary challenge that requires a tailored approach. In this sense, extensive information on biodiversity in general, as well as and on the conservation status of different communities and species that colonize littoral zones in particular, represents an essential resource to make sound decisions in the management of this system.

At the same time, conflicts between potential uses and space availability make essential to develop and apply long term management tools, such as integrated coastal zone management (IZCM), to enhance the protection of coastal resources while to increase the efficiency of their uses. With the aim of promoting such a sustainable development of coastal zones, the European Commission adopted in 2014 the Directive establishing a framework for maritime spatial planning (2014/89/EU). This instrument is based on the Council Recommendation on Integrated Coastal Zone Management (2002/413/EC) and the Protocol to the Barcelona Convention on Integrated Coastal Zone Management, ratified by the EU in 2010. Maritime spatial planning (MSP) and its associated ecosystem-based management approach of the marine environment have gained considerable importance during the last decade (Vanden Eede et al., 2014). Maritime spatial plans aim to map, analyse and organise existing human activities in marine areas, in a coordinated way with a view to ensuring their sustainable development. Thus, among other requirements, an integrated management of the coast needs the characterisation of marine assemblages and species distribution in order to preserve and maintain the integrity and services of ecosystems through the conservation of marine diversity (Douvere, 2008; Douvere and Ehler, 2009). One of the fundamental requirements for such management is the delineation of ecologically meaningful regions and units (Roff and Evans, 2002; Gilliland and Laffoley, 2008).

From both conservation and planning perspectives, one of the first steps is to establish ecologically homogenous types by their abiotic and biotic characteristics. Ecologically sound marine classification is emerging as a useful predictive tool for a variety of related assessment purposes, which facilitates the quantification of the responses of biological patterns and processes to human uses at a certain region. It may also be useful for the development of conservation strategies to preserve species in degraded or fragmented areas, as well as in shifting habitats due to climate change (Rice et al., 2011).

In this context, different methods have been applied to classify coastal waters at regional and larger scales all over the world (e.g. Sherman, 1986; Roff and Taylor, 2000; Mount et al., 2007; Madden et al., 2009). Specifically along the NE Atlantic region several classification systems have been developed; including the European Palaearctic (Devilliers and Devilliers-Terschuren, 1996); CORINE (Commission of the European

Communities, 1991); the European Union Habitats Directive (1992/43/EEC), based on species distribution; OSPAR regions (Dinter, 2001); EUNIS (Davies et al., 2004); the WFD ecoregions for coastal and transitional waters (WFD; 2000/60/EC) and the Marine Strategy Framework Directive subregions (MSFD; 2008/56/EC), which are both based on abiotic attributes; Baltic HELCOM; and the BioMar project (Connor et al., 1997), that encompasses and complements all of them. Nevertheless, these classification approaches greatly vary depending on the physical and biological heterogeneity and on the data availability. There was not a harmonized and standardized classification methodology that can be generally adopted for management and conservation purposes in different regions at diverse scales.

The first approach for a global division was carried out through the Large Marine Ecosystem project (LME), defined in 1984 at the international symposium of the American Association for the Advancement of Science. In the LME proposal marine systems are worldwide divided, based on four linked ecological criteria: bathymetry, hydrography, productivity and trophic relationships. Based on these four criteria 64 major ecosystems are distinguished around the world (Sherman, 1986). One of these ecosystems is the "Iberian Coastal", defined as the continental shelf region of the Eastern Atlantic Ocean lying between the Gulf of Cadiz and the Cantabrian Sea, and bordered by Spain and Portugal.

Afterwards, the CORINE Biotopes project performed an inventory of existing habitats in the European territory, within the general program 1985-1990 CORINE (Coordination of Information on the Environment). This project established a hierarchical classification of the main types of natural habitats based on phytosociological characteristics. Afterwards, the proposed classification was revised and expanded resulting in the catalogue “CORINE biotopes manual. Habitats of the European Community” (Devillers et al., 1991). In this catalogue, Seabed benthic communities are subdivided according to their depth, substrate, geographical location, water movement and biocenosis.

The need of the maintenance of biodiversity of natural habitats and of wild fauna and flora, results in the Habitats Directive. This Directive captures the essence of the Convention on Biological Diversity developed in June 1992 in Rio de Janeiro. This regional approach divides Europe into large biogeographic units and, within these, each state recognizes the delimitation of protected areas due to the presence of certain species and habitats that require special consideration. These areas are called Sites of Community Importance (SCIs). For this purpose, it is necessary to have detailed mapping information of the different habitats represented on the coast in order to classify the SCIS according to their relative value for conservation.

However, the marine environment is poorly represented, in both CORINE and Habitats Directive classifications, because they are based mainly on the knowledge of terrestrial ecosystems. Thereby, in CORINE classification, the intertidal zone is encompassed in the category *Cliffs and rocky shores* and in Annex I of Habitats Directive, the intertidal and subtidal habitats are included in the type “Reefs” (code 1170). This type is defined in the Interpretation Manual of European Union Habitats EUR 25 (European Commission, 2003) as follows “*Reefs can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions*”. These widespread definitions represent a sample of current knowledge gaps on intertidal and shallow subtidal areas.

As evidence of this, the Commission Decision of 7 December 2004, which adopts the sites of Community importance for the Atlantic biogeographical region, includes among the habitats that require more knowledge the above mentioned type 1170 (Annex 3: List of habitat types and species for which it cannot be concluded that the network is either complete or incomplete). It is therefore necessary to study reef habitats, in order to improve the knowledge about the communities, groups and species that colonize these complex ecosystems.

On the other hand, intergovernmental organizations at both regional (Barcelona Convention, OSPAR Convention, Helsinki Convention) and global level (Convention on Biological Diversity) have also highlighted the lack in the definition of the representation of marine species and habitats. In addition, it was required to establish a classification system of habitats from a physical point of view, since the original classifications were strongly settled in phytosociological relations, which raises a problem for non vegetated habitats as some marine environments. In response to proposals received from the OSPAR Biodiversity Committee and the works carried out in the Baltic Sea, the European Environment Agency (EEA) developed the EUNIS classification, within the legislative framework of the Habitats Directive (Annex I). This is a physical, descriptive and predictive classification system that is hierarchically organized. The current classification includes parameters used to distinguish between habitats and descriptive parameters that describe the range of geomorphology, salinity, human impacts and so forth that are encompassed within the habitat (European Environment Agency, 2013). Its hierarchical organization has four basic levels, being in the second of these levels where it is distinguished the habitat type A1 “Littoral rock and other hard substrates”. This level marks the difference between the intertidal and subtidal zone. The system represents a general framework whose future development, by expanding the current definition to more detailed levels, is essential for the effective implementation of the different European Directives, as the WFD and the Habitats Directive, as has been developed along the Spanish coast by the MAGRAMA (2012) through the “Spanish Inventory of Marine Habitats and Species” (*Inventario Español de Hábitats y Especies Marinos*).

The WFD establishes the aim of achieving by 2015 a “good ecological status” for all surface water bodies, including transitional and coastal ones. For this purpose, Member States (MS) have to assess the Ecological Status (ES) of water bodies, assigned through the evaluation of biological, physico-chemical and hydromorphological quality elements. One of the biological quality elements (BQE) in coastal and transitional waters is the vegetation (macroalgae and angiosperms), for which MS have proposed different methodologies for the assessment of ES. In order to enable the consistency of the national assessment systems with the normative definitions (WFD) and the comparison of those between MS, it is necessary to perform an intercalibration (IC) exercise. Hence, the essence of the intercalibration is to ensure that good ecological status represents the same level of ecological quality everywhere in Europe (Annex V WFD). To reduce dissimilarities due to spatial gradients, the intercalibration exercise is performed in a first step inside large geographic areas, such as the North East Atlantic (NEA) (European Commission, 2009a).

The NEA is a very heterogeneous region, with coastal waters which present diverse macroalgae composition, including zones as diverse as the Canary Islands and Norway. In fact, the final results of the first phase of the IC exercise (2005-2008) showed the great difference within the NEA and the difficulty of the establishment of common standardized assessment methods and reference conditions for the vegetation quality elements within this region (European Commission, 2009a). At first, common intercalibration types inside the NEA were agreed for both coastal and transitional water bodies. For coastal waters these were based on the obligatory factors (salinity and tidal range) plus optional factors (depth, current velocity, exposure, mixing and residence time). This resulted on the adoption of six coastal water body types (CW-NEA): 1/26, 3/4, 7, 8, 9 and 10 (European Commission, 2009b). These general types try to integrate the heterogeneity of coastal environments recognized at a more reduced scale within the coastal classifications developed by MS (Moy et al., 2003; Roger et al., 2003; Bettencourt et al., 2004; Spanish Environmental Ministry, 2008; Leonardsson et al., 2009; Ministry of Housing, Spatial Planning and Environment, 2009; Ministère, 2010; NLWKN, 2010).

A general problem in the implementation process of the WFD is the need to find a balance between typologies being too specific (too many types) and being too general (types do not sufficiently reflect natural variability) (Hering et al., 2010). In the case of the NEA, because of the broad nature of some typologies (CW-NEA1/26), further subdivisions seemed to be necessary in order to produce results. The intercalibration exercise is carried out within “common intercalibration types”, but compositional differences in biological communities still remain within a common type. Therefore, an adjustment is needed to remove the effects of such biogeographical discrepancies that can make comparability difficult (Guinda et al., 2008). The recognition of suitable “common types” was an urgent need and a preliminary task before intercalibration of classification methods was finalized (European Commission, 2009c). Therefore, in the second phase of the IC exercise (2008-2011) further work in this field was proposed by experts in order to review the common intercalibration types defined in the first IC phase.

For river vegetation elements within WFD, an interesting approach that considers "subtypological variants", characterized by distinct physical features and biological communities, has been developed (European, 2009a). The proposal tries to deal with diverse patterns of species dispersal, climatological gradients or regional specificities within a common intercalibration type. Bearing this in mind, it should be tried to provide suitable information to justify the establishment of physically homogeneous coastal zones for potential distribution of macroalgae under the NEA coastal area.

In general, the management and protection of coastal areas take place at different spatial scales, ranging from broad to fine ones (Connor et al., 2006). The availability of classifications at different scales represents an essential element for an appropriate management and protection of coastal areas (Bianchi et al., 2012), since it allows to develop action plans at levels of detail that are both ecologically meaningful and appropriate to the integrated management needs. This feature is particularly important for many policies and management initiatives which are characterised by a range of scales, with goals set at national o regional domains but implemented at more local scales (Rice et al., 2011). Many efforts at managing environmental resources in coastal waters attempt to conserve species and to preserve the structure and processes of habitats at a medium or large area (e.g., Zacharias and Roff, 2000; Diaz et al., 2004; Gregr and Bodtker, 2007). These biogeographic approaches are typically more useful for understanding species distribution patterns and dynamics. Thus, research efforts need to be increased in order to encompass global studies (Lawton, 1996). This search for generalities can be handled through ecological classifications, that permit the collation, unification and synthesis of large areas data, providing an objective basis for analyses and a useful tool for conservation efforts (Snelder et al., 2007). On the other hand, studies of marine ecosystems need to also be addressed on a case by case basis, since each zone is unique in terms of locally specific environmental, social and economic characteristics (Reis, 2014). Therefore, classifications at a finer level of resolution may be useful for conservation planning and for the implementation of effective biomonitoring programs in a particular region (Hawkins et al., 2000). Additionally, in terms of climate change, many mitigation and adaptation actions are quite site-specific due to the different vulnerabilities of local communities and ecosystems (McCarthy et al., 2001).

On the basis of all the above mentioned, it can be observed that different international directives and conventions use different classifications, which complicates the management of the different objectives of conservation and improvement of coastal aquatic ecosystems established therein. It is therefore necessary to establish a homogenous classification at different scales that takes into account both the physical characteristics and those related to biological communities that colonize this environment. This classification system would allow to deal with accurate diagnostic and assessment criteria of their state of conservation that, ultimately, allow for their sustainable management at the required level of definition.

1.2. Macroalgae communities description

Intertidal macroalgae communities associated with intertidal rocky shores are very relevant from an ecological and a scientific point of view. From an ecological perspective, it has been shown that despite their small relative representation (i.e., they occupy a small area in relation to other coastal ecosystems), they are vital for the ecological functioning of coastal zones (Lubchenco et al., 1991), as they are an integral component of ecosystems, being the primary producers that provide food, habitat and shelter for many marine organisms (Cavanaugh et al., 2010). In addition, they act as a physical structure modifying hydrodynamic forcing and sediment transport (Madsen et al., 2001; Venier et al., 2012). Scientifically, the composition and distribution of these assemblages have been widely studied, as they are the basis of rocky substrate reefs.

The current zonation patterns of the intertidal zone were described for the first time in the last decade of the 19th Century, in European and North American coasts. At this time the studies were essentially descriptive, without actually investigating the causes of zonation patterns distinguished along the coasts. During the second half of the 20th Century information about zonation patterns was synthesized by authors as Stephenson and Stephenson (1949; 1972) and Lewis (1955), showing that these patterns are constant in the different coasts of the world, although the tidal level and the width of belts depend on many factors, both physical and biological. Currently, there are numerous studies and compilations that describe the distribution patterns of intertidal communities and their variation worldwide (e.g., Lüning, 1990; Raffaelli and Hawkins, 1996; Knox, 2000). Although these patterns are called "universal" there are difficulties in defining intertidal areas according to organisms (Lobban et al., 1985), since flora and fauna change geographically and temporally.

The works carried out for the analysis of macroalgae communities in the different areas of interest in this study (NE Atlantic, N and NW Iberian Peninsula and coast of Cantabria) are described hereafter.

Along the NE Atlantic coasts, general distribution patterns of macroalgae species are reasonably well-known (e.g., van den Hoek, 1975; Lüning, 1990). However, most studies and compilations analyze species distribution for single locations or countries and not for wide bio-geographical regions, as for example Juanes & Sosa (1998) in Spain; Gaspar et al. (2012) in Portugal; Lewis (1955) in UK; Jaasund (1965) in Norway; van den Hoek & Donze (1966) in France; and Munda & Markham (1982) in Helgoland (Germany). Despite all these studies, a comprehensive single and standardized inventory all along the NEA region does not exist, which hampers an adequate approximation of intertidal macroalgae species distribution for marine management purposes. In addition, the strong knowledge of species composition and biodiversity around this area is of utmost importance to maintain the long-term suitability of ecosystems, allowing a better evaluation of changing environmental conditions as global warming (Verfaillie et al., 2009).

The entire Bay of Biscay is a transitional area located between the southern warm region (Cantabric sea) and the northern cold region (French Brittany) (van den Hoek, 1982a; Lüning, 1990) in terms of the distribution of macroalgae. There has been general knowledge of the distribution of macroalgae along the southern European region since the first half of the twentieth century (e.g., Sauvageau, 1897; Miranda, 1943; Fischer-Piette, 1963). These pioneering studies were essentially floristic inventories in which the meridional gradient along the Cantabrian coast (West-East) was evident, where Bay of Biscay waters are warmer and are subject to markedly different ocean dynamics. Hence, two major areas were observed on this coast, clearly differentiated by their algal composition, with a transition zone located around *Peñas Cape* (Anadón and Fernández, 1986). At the same time, the studies on zonation carried out by Miranda (1931) were very important, establishing detailed zonation models based on factors such as wave exposure and substrate type. In recent decades, several studies have shown temporal variations with respect to that general pattern, highlighting the importance of certain natural and anthropogenic factors in the distribution of seaweed species (Anadón and Niell, 1981; Anadón, 1983; Juanes et al., 2007; Lima et al., 2007; Guinda et al., 2008; Juanes et al., 2008; Lobón et al., 2008; Díez et al., 2009; Fernández, 2011; Guinda et al., 2012; Duarte et al., 2013). It has been observed that when a large size algae of the order Fucales is missing, its dominant role is assumed by another algae of the same order (as for example *Bifurcaria Bifurcata*) but, if the latter possibility does not exist, a generalist specie from the community is implanted (Niell, 1980; Fernández and Niell, 1981, 1982; Anadón, 1983; Fernández et al., 1983).

In a complementary way, several studies were carried out at different levels of the intertidal zone in order to describe aspects related with the structure, composition and ecology of the intertidal or shallow subtidal communities, as for example *Saccorhiza polyschides* (Fernández, 1980), *Gelidium latifolium* (Juanes, 1983; Juanes and Fernández, 1988), *Bifurcaria bifurcata* (Fernández et al., 1983) and *Corallina elongata* (Sierra and Fernández, 1984). Moreover, recent studies about the anthropogenic impact on coastal communities have improved the knowledge of the macroalgae distribution, such as those made after the accident of the oil ship Prestige in the Cantabrian coast (GESHA, 2006; Juanes et al., 2007; Lobón et al., 2008; Díez et al., 2009). In addition, the responses of macrolagae communities to gradual variations in environmental conditions related with climate change have been analyzed, on view of the evidence that here the boundaries of some species have moved east- and westwards during the last century (c.f. Arrontes, 2002; Fernández, 2011).

Specifically in the coast of Cantabria, recently research effort has been developed on the structure of subtidal communities (Guinda et al., 2012), but no detailed study has been conducted concerning the intertidal communities and their relationship to abiotic variables. Therefore, the information regarding the macroalgae species distribution along this coast is of interest in itself, since previous works are very scarce as compared with other proximal regions: Asturias (Anadón and Niell, 1981; Fernández and Niell, 1982; Anadón, 1983), Basque Country: (Borja et al., 1995; Díez et al., 1999; Gorostiaga et al., 2004) and Galicia (Bárbara et al., 2005).

Despite all these studies, there has never been a comprehensive and homogeneous inventory (taxonomy, season, relation with physical variables, etc.) that provides adequate knowledge of the current distribution of macroalgae species, from the European coast to the Cantabria province. Such information should be available in each area of interest and with a level of accuracy in accordance to the study scale. This type of information would be very useful for marine spatial management and a key element for the validation of any kind of classification developed in these coastal areas.

1.3. Distribution patterns of macroalgae related with physical factors

In the previous section studies on macroalgae populations of the coastal zone and its distribution have been considered. Macroalgae, as sessile organisms, respond directly to the abiotic and biotic aquatic environment (Murray and Littler, 1978) and zonation is one of the most obvious features in the intertidal rocky shores. Thus, the interaction between physical and biotic factors in this area has been frequently analyzed and it is well known that intertidal species vary due to natural abiotic influences and biological interactions.

The temperature is critical for all organisms because of its effect on the physiological activities and molecular properties and, hence, in almost all biological processes associated. Furthermore, drying effects determine the position in the upper intertidal limits of many species. The important role of the temperature is therefore recognized as one of the most important environmental factors directly responsible for differences in the geographical distributions of marine organisms resulting in the delimitation of large biogeographical regions (van den Hoek, 1982a, 1982b; Breeman, 1988).

But there are other variables determining the geographical seaweed distribution, such as water movement, light and salinity (Lüning, 1990; Rinne et al., 2011; Spatharis et al., 2011). The intensity of wave action is one of the main agents that control the structure of communities along the coast (Dayton, 1971; Levin and Paine, 1974; Dayton, 1975; Sousa, 1984). This factor determines both the width of each belt and the organisms found. Wave action interacts in different ways with the distribution of communities. In regard to biological characteristics, wave action affects the ability of physiological and morphological adaptation of the organisms, for example by limiting the activity and distribution of browsers and predators (Lubchenco et al., 1991), or by generating available spaces for the colonization of new organisms (Dayton, 1971; Levin and Paine, 1974). Besides the disturbance caused by the wave power, it has the ability to cause erosion and transport of the substrate, carrying suspended particulate matter of different size. Aquatic organisms can also be exposed to the air when strong waves modify the hydrodynamic regime.

Tidal currents are closely related to the previous factor, they determine the distribution of communities by providing intermediate conditions between exposed and protected areas. Therefore, in areas with high tidal current velocities macroalgae developed special morphologies to tolerate rapid flows (Lewis, 1964). In addition, the tidal range determines the width of the intertidal zone and the specific distribution of communities along the shore (Lewis, 1955).

Among the climatic factors that affect the distribution of organisms, solar radiation is a key factor (Hanelt et al., 1993), providing the initial energy for photosynthesis and, therefore, for all the biological processes associated. Light is also the signal for many events in the life cycle of seaweeds (reproduction, growth and distribution) and influences the behaviour and activity of most animal species. Excessive radiation shows negative effects on macroalgae at molecular, physiological and ecological levels (Larkum and Wood, 1993; Häder and Figueroa, 1997; Wahl et al., 2004) and produce photoinhibition (Hanelt et al., 1993). On the other hand, it is also critical the low intensity of this factor, because it could retard or eliminate the recruitment of some species (Borja and Gorostiaga, 1990).

Finally, other physico-chemical variables are also important in the development of communities, such as salinity and nutrient concentrations (Lüning, 1990; Wallentinus, 1991). At broad areas, salinity varies mainly due to freshwater inputs, particularly in areas close to large estuaries or particular seas. Among nutrients, phosphorus and, especially, nitrogen are limiting in seawater (De Boer, 1981). The main sources of these nutrients in the ocean are upwelling processes and the movement by convection from the water sub-surface. These are regimes that, anyway, are also marked by low surface temperatures. Along the coast of a particular region, the flora and fauna are found in an environment that is relative constant to these physico-chemical factors, except those areas under the effect of point sources discharges.

Focusing on geomorphological features, different variables may affect the sessile assemblages in different ways. The aspect (direction of the surface floor), slope and texture of the surface may cause differences in drainage, evaporation, sedimentation and shade, modifying the characteristic patterns of the intertidal zone (Lobban et al., 1985; Rinne et al., 2011). Roughness may also influence composition through indirect effects on herbivore activity (Jenkins et al., 2008). The type of substratum affects the retention of heat and water, which makes algae grow or survive better (McGuinness and Underwood, 1986; McGuinness, 1989), causing differences among assemblage structures and the covers of individual taxa of algae (Green et al., 2012). On the other hand, substratum nature could also affect turbidity, as it is higher when the substrate is extremely fine (Dixon and Irvine, 1977). In general, the agents that cause the differences in assemblages can change in their intensity due to the geomorphology of the rocky coast (Bird, 2008).

The majority of rocky shores include sand interspersed with the biota. Therefore, fluctuations in the amount of sand also determine the coverage of organisms (Littler, 1980; Littler et al., 1983). In general, the excess of sediment harms organisms, both sessile and mobile, through three mechanisms, choking, physical damage by friction and interstitial environment modification (Devinny and Volse, 1978). However, there are also other studies (Littler and Littler, 1981; McQuaid and Dower, 1990) that demonstrate how perturbations of this type, if they are located, increase the diversity by creating a mix of plots in different stages of succession (mosaic structure).

In spite of the important role played by geomorphological characteristics in explaining patterns in the structure of rocky communities (e.g., Cerrano et al., 1999; Bavestrello et al., 2000), relatively little attention has been paid to the study of these types of interaction, except for those focused on the settlement of larval stages of fauna species depending on rock type (Fischer, 1981; Anderson and Underwood, 1994; Schiaparelli et al., 2003). Although seaweeds are among the most obvious and ecologically important components of rocky shore communities worldwide (Lubchenco et al., 1991), until now little has been known about the influence of substrate mineralogy and geomorphology on their distribution.

Interactions between algal species and between algae and herbivores may play an important role in the distribution and abundance of seaweeds (Lubchenco and Gaines, 1981; Hawkins et al., 1992), as happens with anthropogenic pressures (Schramm and Nienhuis, 1996; Juanes et al., 2008). However, these factors should be studied at a very high level of detail and are not easily quantified in a homogenous way at a global or regional scale.

In summary, several abiotic and biotic factors determine the distribution and structure of coastal benthic communities, depending on the main drivers of ecological processes and patterns at the spatial scale of interest (Levin, 1992). At a global scale, temperature and solar radiation are mainly responsible for biogeographic differences (van den Hoek, 1982a; Lüning, 1990). At higher scales (e.g., at a regional scale), factors such as exposure to wave action, tidal range, salinity and nutrients may play a major role in the distribution and structure of intertidal communities (Kautsky and van der Maarel, 1990). However, at a local scale some of these variables do not vary significantly; therefore other factors, such as geomorphological characteristics and vertical height, seem to affect species distribution (Schoch and Dethier, 1996; Díez et al., 2003; Chappuis et al., 2014). The successful protection and management of marine diversity, the assessment of anthropogenic impacts and the restoration of altered ecosystems rely largely on the understanding of the processes and factors that structure biological assemblages (Chapman, 1999). Therefore, it is important to establish the significance of each variable at different scales of analysis, as well as the interaction between them as a decisive element in the distribution of the different organisms.

1.4. Cartography systems

1.4.1. Physical characterisation

Because of the predictive ability of the above mentioned abiotic variables it is important to improve the systems of physical characterisation, as an essential tool to standardize and amplify the importance of community studies. During the last decade, the rapid development of hydroacoustic techniques and remote sensing has expanded the range of possibilities in the field of mapping intertidal and subtidal communities. In this sense, an important area of work related to the characterisation of "potential habitats" based on physical environmental predictors arises.

Within the line of work of coastal mapping with hydroacoustic techniques and remote sensing, several INTERREG projects have been developed in different regions of the European Union: the MESH project (Connor, 2009) in NE Europe; the BALANCE project (Reker et al., 2009) in the Baltic Sea; and the HABMAP project (Wilson and Ramsay, 2009), that has mapped the seafloor of the southern Irish Sea. In this line, there are several projects carried out by the Joint Nature Conservation Committee (JNCC), among which highlights the UKSeaMap project, where maps of seabed landscapes and of seasonal characteristics of the column water were created for UK waters.

Although remarkable progress has been achieved in this field, the application to large areas represents a significant work effort, since punctual seabed information cannot be extrapolated to wider sections. Therefore, there is a need to implement predictive tools that optimize the use of accurate mapping technologies. Quantifying the descriptors in a standardized way and with an adequate level of definition for the specific objective of the classification has previously constituted a bottleneck for some physical classifications. However, it is currently possible to obtain a standardised and extensive environmental characterisation based on satellite observations and the mathematical modelling of physical conditions, which presents a global coverage and can also provide information with the appropriate level of accuracy for different purposes (Smith et al., 1998; Hooker and McClain, 2000; Li et al., 2001; Reguero et al., 2012). This aspect would result in the development of a coastal area classification system, which serves as the basis for predicting potential habitats of the different communities.

1.4.2. Biological characterisation

In general, until the last decade the first mapping approaches were focused directly on making an inventory of communities. Among these procedures, four types of sampling techniques can be distinguished: based on areas, based on transects, the fishing charters and the remote sensing techniques. The first technique used was the one based on areas, this consists of the harvest of different surfaces, which biomass is then weighted and extrapolated to the total area theoretically occupied by the species.

An alternative methodology that improved the prediction of these studies was the one proposed by Mann (1972), using the sampling technique based on systematically located transects. This work, in which macroalgal communities were mapped in the coast of Nova Scotia (Canada), was a significant contribution, by the incorporation of errors calculation to the estimate abundances of each species. In the 90s, many of the works carried out for the assessment of algal resources in the Bay of Biscay coast were developed with this method (e.g., Anadón and Fernández, 1988; Borja, 1988; Llera et al., 1988; Juanes and Gutiérrez, 1992).

In the 90s, characterisation methodologies that incorporated prospecting systems for large areas emerged. These methodologies were carried out with commercial interests, although in many cases they had serious differences in the estimation of actual abundances (Llera et al., 1988; Catoira, 1990, 1991, 1992). Similarly, techniques based on remote sensors began to be used, particularly focused on the characterisation of large intertidal communities in transitional waters. These techniques represent the precursor elements of the approaches used today.

On the other hand, trying to reduce the costs associated with these works, several authors have underlined the need to develop methodologies which, without losing their scientific rigor, are economically reasonable and easy to apply in order to carry out extensive management or monitoring works (Panayotidis et al., 2004; Borja, 2005). In this sense, the use of non-destructive sampling methods, included among the recommendations of the International Council for the Exploration of the Sea (ICES, 2001), supposes the absence of laboratory work, simplifying data processing and notably reducing the total monitoring costs (Ballesteros et al., 2007; Puente and Juanes, 2008).

Nowadays, the two non-destructive methods most commonly used are visual inventory quadrats and wire frame still photography (Parravicini et al., 2009). In both cases, the quantitative estimation consists normally in the evaluation of biotic cover, i.e., the percent of substratum surface occupied by each organism. Advantages and disadvantages are associated with each of the two methods. Photography provides permanent records, allows software image analyses, reduces the time of sampling and does not require an expert in species identification (Guinda et al., 2014). By contrast, the analysis of images is time consuming, and may depend greatly on the quality of the photos. On the other hand, visual inventories may be more affected by observer subjectivity (Meese and Tomich, 1992), although the identification of taxa through direct observation in the field is often more effective than a later time on photos and allows recognizing organisms hidden by taller species.

Considering all these aspects, *in situ* identification of species combined with photography sampling techniques for cover estimation, appears to be an effective strategy for the rapid and correct assessment of intertidal macroalgae assemblages in order to carry out extensive management and characterisation works.

1.5. Classification systems

The increasing anthropogenic pressures on the marine environment (Halpern et al., 2008) highlight the need of a proper management and control of resources in coastal areas. Successful conservation plans require the characterisation of marine assemblages and species distribution through different areas. In this sense, classifications are a fundamental tool that allows the establishment of specific action plans needed to reach preservation goals.

Given the influence of physical factors on the distribution of species (Roff and Taylor, 2000), it could be advantageous to use these variables in coastal classifications, especially in global scale ones, due to the possibility of a continuous data acquisition against the lack of homogeneous reliable biological information all around a large area. Based on such assumptions it is possible to consider that more easily measured physical or chemical variables, which relies increasingly on remote sensing (Allee et al., 2014) and models (e.g., Parravicini et al., 2009), could be used as surrogates of biological patterns.

In the last decade, the ability of these variables as potential predictors of habitats for different communities has been applied to coastal system classifications. Currently, there are numerous schemes available for the classification of national coastal waters (e.g., Dethier, 1990; Roff and Taylor, 2000; Connor et al., 2004; Lombard et al., 2004; Mount et al., 2007; Snelder et al., 2007; Madden et al., 2009; Verfaillie et al., 2009). The variables commonly used in the most relevant classifications are wave exposure, zonation, substrate composition, topography, currents and temperature. Table 1.1 provides a general review of coastal classifications, including the variables used and the study area. However, these classifications greatly vary depending on the region where they were developed, on the physical and biological heterogeneity and on the availability of data (Valentine et al., 2005). In addition, main results of these classifications are represented as habitat patches instead of continuous coastal areas, as necessary for the several management purposes.

Table 1.1. Comparative analysis of the variables used in classifications developed in different geographic areas.

	EUROPE							AMERICA							OCEANIA			AFRICA
Variables	**ZES** (Bouma et al., 2005) Holland	**Verfaille et al.** (2009) Belgium	**Connor et al.** (2004) UK, Ireland	**RAC/SPA** (2006) Mediterranean	**EUNIS** (Davies et al., 2004) UE	**WFD** (2000/60/EC) UE	**CORINE** (Devillers et al., 1991) UE	**CMECS** (Madden et al., 2009) N America	**Dethier** (1990) Washington	**Valentine et al.** (2005) NE America	**Merkel et al.** (2002) San Diego	**BCMEC** (MSRM, 2002) British Columbia	**Roff and Taylor** (2000) Canada	**Green et al.** (2007) California	**NISBHCS** (Mount et al., 2007) Australia	**IMCRA** (1998) Australia	**Snelder et al.** (2007) New Zeland	**NSBA** (Lombard et al., 2004) South Africa
Temperature			x	x		x						x			x	x	x	x
Solar radiation			x												x		x	x
Wave exposure	x		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Currents	x	x	x			x			x	x		x	x		x		x	x
Energy		x	x					x										
Tidal range			x			x		x			x		x			x		
Substrate	x	x	x	x	x	x			x	x	x		x	x	x			x
Zonation	x		x	x	x	x	x	x	x	x	x	x		x	x		x	x
Sediment composition	x	x	x	x			x		x	x			x	x	x	x		x
Topography		x	x					x		x	x	x	x	x	x	x	x	x
Geology (aspect, slope...)		x	x							x		x		x	x	x		
Turbidity			x			x												
Salinity	x		x	x		x						x	x					x
Oxygenation			x															
Nutrients													x					
Stratification						x						x	x					

Table 1.1. Continued.

	EUROPE							AMERICA							OCEANIA			AFRICA
Variables	**ZES** (Bouma et al., 2005) Holland	**Verfaille et al.** (2009) Belgium	**Connor et al.** (2004) UK, Ireland	**RAC/SPA** (2006) Mediterranean	**EUNIS** (Davies et al., 2004) UE	**WFD** (2000/60/EC) UE	**CORINE** (Devillers et al., 1991) UE	**CMECS** (Madden et al., 2009) N America	**Dethier** (1990) Washington	**Valentine et al.** (2005) NE America	**Merkel et al.** (2002) San Diego	**BCMEC** (MSRM, 2002) British Columbia	**Roff and Taylor** (2000) Canada	**Green et al.** (2007) California	**NISBHCS** (Mount et al., 2007) Australia	**IMCRA** (1998) Australia	**Snelder et al.** (2007) New Zeland	**NSBA** (Lombard et al., 2004) South Africa
Organic carbon		x	x															
Water quality			x															x
Residence time						x		x		x								
Continental shelf								x			x							x
Ecologic region						x		x			x							
Coral reef															x			
Ice cover													x					
Geographic location		x				x	x						x					
Anthropogenic influence			x					x		x	x							
Recover capacity										x						x		
Chlorophyll																		
Biological data							x	x		x				x	x	x		x

Most of the classifications, both national and international, are designed to organize geospatial information in a hierarchical network, as is the case of Australian (Last et al., 2010) and North American (Madden et al., 2009) coastal waters. These hierarchical classifications divided main groups into subordinate classes, allowing to include new descriptive factors and/or to focus on a more reduced area with a higher spatial resolution. The problem is that each classification has its own objectives and data organization. These differences make difficult to use the schemes in different places and, in general, many of the classification systems proposed in the past fifty years are either too vague or too detailed, referring to the abiotic characteristics in very broad terms. According to Fraschetti et al. (2008), there are three major reasons for the lack of a homogeneous and universal classification of coastal habitats: lack of common vocabulary for the different habitat types; marine environments are less favourable than the terrestrial ones for precise data collection about the distribution and extension of habitats; and the lack of a unique and understandable system for the identification and classification of marine habitats.

On the other hand, most of the classification methods based on physical variables do not include biological validation, given the sparseness of biological data and the difficulty of gathering it. If the objective is to understand different physical structures, then these classifications may be sufficient. However, if these classification systems claim to describe biogeographical regions and allow the establishment of ecological typologies, it is necessary to test and validate the biological suitability of the different classes obtained (Gregr et al., 2012). An important criterion is an objective statistical demonstration, which proves that the derived classification units are significantly similar or different, based on both environmental and biological characteristics (Valesini et al., 2010). However, this biological criterion is lacking in most of the existing coastal classifications.

In summary, the development of a classification system must first take into account the spatial domain and the working scale required for the specific research objective. Then, additional important aspects such as those associated with the spatial resolution (e.g., grid size), the type of indicator (e.g., significant wave height vs. shear stress), and the source of physical (e.g., satellite vs. modelling) or biological data (e.g., qualitative vs.

quantitative abundances) should be established. This way, it would be possible to develop a hierarchical procedure suitable for analysing the variability in the environmental conditions in different coastal areas and scales. A classification approach could be established along the NE Atlantic coast in order to observe patterns of variability analysing the entire area. Then, further downscaling analyses may be carried out to consider the distribution of biotic and abiotic variables on a higher scale with a higher level of definition. These analyses might look for variability at certain ecotones, such as those at well-known distribution limits for representative species according to previous scales.

Considering all these aspects, the development of a suitable ecological classification system at different scales is a key point for the development and implementation of the different management actions. The accurate knowledge provided by this classification will facilitate the specific quantification of the responses of patterns and processes to human uses at a certain region. Thus, it will be useful in the implementation of different legislation, as well as for the general assessment of coastal ecosystems.

1.6. Objectives of the thesis

The general objective of this thesis is to develop a methodology for the classification of intertidal rocky shores at European (Northeast Atlantic coast), regional (North and Northwest Iberian Peninsula coast) and local (Cantabrian coast) scales, through the relation between abiotic characteristics and macroalgae species distribution. The specific objectives of this thesis are focused on the following aspects at each of the scales:

1) To select the most suitable and available physical variables and to analyze how they influence the distribution and structure of rocky intertidal macroalgae communities.

2) To elaborate a quantitative classification of the coast based on the physical variables previously selected.

3) To analyze and characterize the distribution of intertidal macroalgae species along the coast, providing homogenous and standardized information.

4) To test the agreement between the physical classification obtained and the distribution of intertidal macroalgae observed.

1.7. Layout of thesis

The structure of the thesis is organized as follows:

In the Chapter I the motivations for the research and the background to the research of the studied aspects are presented. At the end of this chapter the specific objectives designed to answer the raised questions are outlined and the structure of the thesis is described.

The following five chapters (II, III, IV, V, and VI) address the objectives of the thesis. Each of the chapters includes an abstract, a brief introduction, methodology, results and discussion sections, constituting edited versions of different articles published in or submitted to SCI journals. A brief abstract of the investigations conducted in each chapter is described as follows (Figure 1.1):

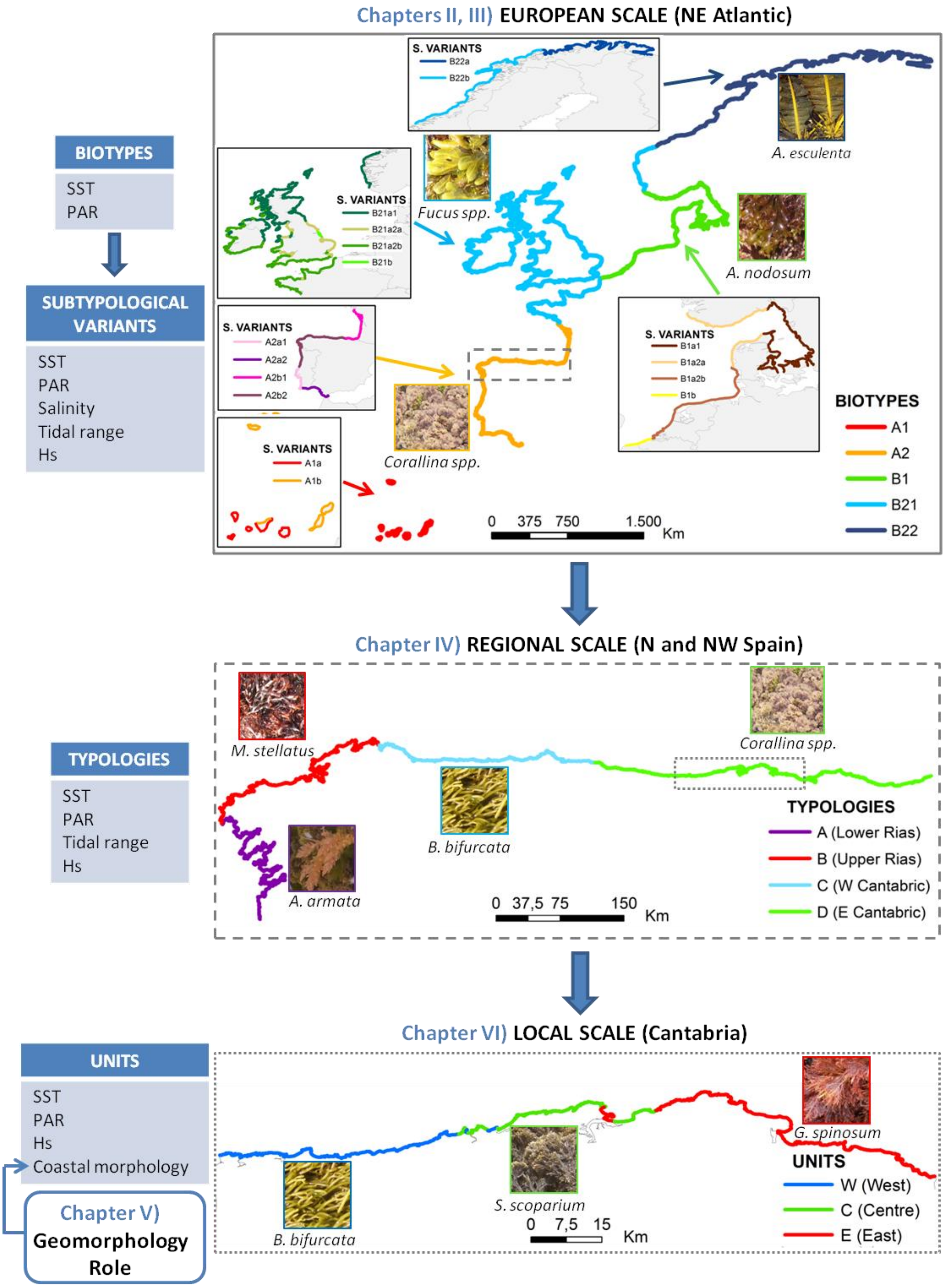


Figure 1.1. Graphical summary of the studies carried out (ecological classifications at different scales).

Chapter II. Physical classification at European scale

In this chapter a classification system of coastal wasters based on abiotic variables is developed along the North East Atlantic region. Physico-chemical factors (temperature, radiation, exposure to wave action, tidal range and salinity) have been calculated in consecutive points situated in a parallel line to the coast. Firstly, biotypes have been identified as broad geographic regions. Then, variability of environmental conditions inside these biotypes (subtypological variants) has been also analyzed. The feasibility of this methodological approach as a useful tool for the assessment of the actual homogeneity of coastal environments at a European scale has been tested.

Chapter III. Biological validation at European scale

The biological validation required to support the ecological meaning of the physical typologies obtained in the previous chapter is accomplished in this chapter. A semi-quantitative data base of intertidal macroalgae species occurring in the coastal area between Norway and the South Iberian Peninsula has been generated. Ordination and classification multivariate analyses have been applied to study the distribution of macroalgae species. These results have been compared with physical classifications in order to test their biological significance.

Chapter IV. Coastal classification at regional scale

This work proposes a downscaling methodology for the classification of coastal waters at a regional scale. The N and NW Spanish coastline has been classified according to physical variables (temperature, radiation, exposure to wave action and tidal range) using techniques adapted to the study scale. To validate the classification with biological data, intertidal macroalgae have been simultaneously and homogeneously sampled. The ecological significance of the physical typologies has been tested by different statistical analyses.

Chapter V. The role of geomorphology in macroalgae distribution at local scale

In this chapter the relation between geomorphological variables (active processes, coastal morphology, coastal orientation and lithology) and rocky intertidal macroalgae species at a local scale is analyzed. Information about both cover of seaweed species and geomorphological features has been obtained in several points along the coast of Cantabria. The study of their relation has been carried out through multivariate analysis and logistic regression at three levels of organization: community descriptive parameters, community composition and species preferences.

Chapter VI. Coastal classification at local scale

In this chapter an ecological classification at a local scale is developed as a useful tool for conservation planning and for the implementation of effective programs in a particular region. The methodology previously established at smaller scales has been adapted to classify the coast of Cantabria (N Spain). A hierarchical classification has been carried out at two levels, using the variables temperature, radiation, exposure to wave action and coastal morphology. The ecological significance of the physical units and subunits has been tested by intertidal macroalgae data.

Finally, general conclusions and future research lines are described in Chapter VII.

Chapter II

Physical classification at European scale

Chapter II. Physical classification at European scale

This chapter is an edited version of the research article published in the journal Estuarine, Coastal and Shelf Science, vol. 112, pp. 105-114, by Ramos, E., Juanes, J.A., Galván, C., Neto, J.M., Melo, R., Pedersen, A., Scanlan, C., Wilkes, R., van den Bergh, E., Blomqvist, M., Kroup, H.P., Heiberg, W., Reitsma, J.M., Ximenes, M.C., Silió, A., Méndez F.J., González, B., in 2012 with the title "Coastal waters classification based on physical attributes along the NE Atlantic region. An approach for rocky macroalgae potential distribution".

Abstract

According to requirements for intercalibration of assessment methods of vegetation quality elements along the North East Atlantic region, within the scope of the European Water Framework Directive (WFD), a better classification system of coastal regions was needed. To accomplish that goal, a quantitative classification approach was launched in order to establish common typologies for assessment of this biological quality element. This was preliminarily based on a physical classification of the coastal waters that included two consecutive steps, a first one devoted to the establishment of "biotypes" (large areas), and a latter one dealing with recognition of the variability within biotypes ("subtypological variants"). The NEA region coastline was subdivided into 550 consecutive stretches (40 km long). Then, physical variables (sea surface temperature, photosynthetically active radiation, wave exposure, tidal range and salinity) were calculated in reference points of each stretch, 5 km from the coast. This information was based mostly on satellite acquired data, using specific procedures proposed in this work. Physical typologies of NEA coastal waters were obtained by statistical analyses. Five different biotypes were selected (i.e., coastal sectors of the European coast) by national experts as baseline information to be used on intercalibration of assessment methods for vegetation within the WFD. Variability of environmental conditions on those biotypes was also analyzed and compared with previous classifications carried out at the national scale. Results from this study showed the feasibility of this methodological approach as a useful tool for assessment of the actual homogeneity of coastal environments.

2.1. Introduction

The North East Atlantic (NEA) is a very heterogeneous region, with coastal waters which present diverse vegetation composition, including zones as diverse as the Canary Islands and Norway. The intercalibration exercise within the WFD (IC) is carried out within "common intercalibration types", but compositional differences in biological communities still remain within a common type. In fact, the recognition of suitable "common types" was an urgent need and a preliminary task before intercalibration of classification methods can be finalized (European Commission, 2009c). Therefore, further work was needed in this field in order to review the common intercalibration types defined in the first IC phase (2005-2008).

The biogeographical variation is due, partly, to the climatic gradient across countries, being temperature one of the most important parameters (van den Hoek, 1982a, 1982b; Breeman, 1988). There are other variables determining the geographical seaweed distribution, such as light, water movement and salinity (Lüning, 1990; Rinne et al., 2011; Spatharis et al., 2011). Furthermore, it could be advantageous to use these physical factors in global scale classifications, due to the possibility of a continuous data acquisition against the lack of homogeneous reliable biological information all around a large area. Based on such assumptions it is possible to consider that physical characteristics might be used as surrogate indicators of ecological processes. The development of classification systems based on those proxies would allow for the establishment of different geographical zones for IC macroalgae purposes in NEA region.

The European Community and International Conventions have elaborated different classifications along the European coast, as the WFD ecoregions for transitional and coastal waters, the Marine Strategy Framework Directive subregions (MSFD; 2008/56/EC), the OSPAR regions and the EUNIS system (Davies et al., 2004). Apart from that, several approaches have been developed to classify national coastal waters (e.g., Dethier, 1990; Roff and Taylor, 2000; Connor et al., 2004; Lombard et al., 2004; Mount et al., 2007; Snelder et al., 2007; Madden et al., 2009; Verfaillie et al., 2009). However, main results of these classifications are represented as habitat patches instead of continuous coastal areas, as necessary for the IC exercise.

For river vegetation elements, an interesting approach that considers “subtypological variants”, characterized by distinct physical features and biological communities, has been developed (European Commission, 2009a). The proposal tries to deal with diverse patterns of species dispersal, climatological gradients or regional specificities within a common intercalibration type.

Bearing this in mind, as the main goal of this chapter, it was tried to provide suitable information to justify the establishment of physically homogeneous coastal zones for potential distribution of macroalgae under the NEA coastal area. The physico-chemical characteristics were used to establish such a quantitative classification, the “biotypes”, which, after a more detailed analysis reflecting the variability at this scale (biotypes), should be able to identify likely “subtypological variants” for these coastal areas.

The integration of current technical advances from this research field, and following a four-step procedure (Figure 2.1), constituted the starting point for the establishment of suitable biotypes along the NEA region.

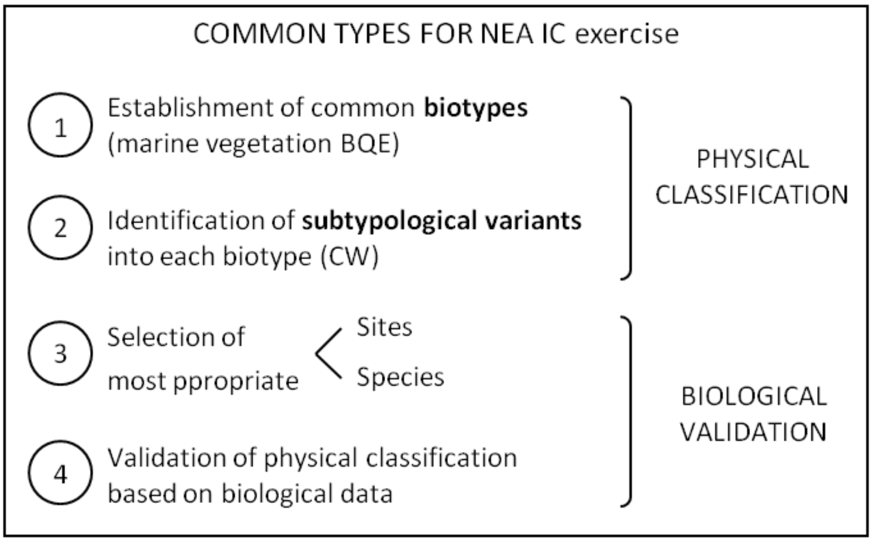


Figure 2.1. Summary of the main steps proposed for the establishment of common IC types.

2.2. Material and methods

2.2.1. Study area

This study was carried out in the European NEA coast. This region extends from the longitude 39° W to 31° E and from the latitude 27° N to 71° N, including parts of the coastline of the following countries: Belgium, Denmark, France, Germany, Ireland, Netherlands, Norway, Portugal, Spain, Sweden and United Kingdom. Because of its wide extension, the NEA region has a very heterogeneous climate, from desert climate (BW) in Canary Islands to continental subarctic (Dfc) and even tundra climate (ET) in Norway, according to Köppen classification (1936).

In order to apply a uniform procedure for the division of the entire coast, sections of equal length were established by cutting a smooth digital coastline at global scale every 40 km using ArcGis (ESRI). This length for the coastal stretches was considered the optimum, taking into account the global scale of the entire study area. The boundaries of the 550 stretches obtained were projected to a parallel line to the coastline (5 km away from the coast) and physical variables were calculated in the central point of each of these offshore sections. Thus, a serial number, beginning at the Strait of Gibraltar (Iberian Peninsula), was assigned to each section as well as to the points where the variables were calculated (reference points hereinafter) (Figure 2.2).

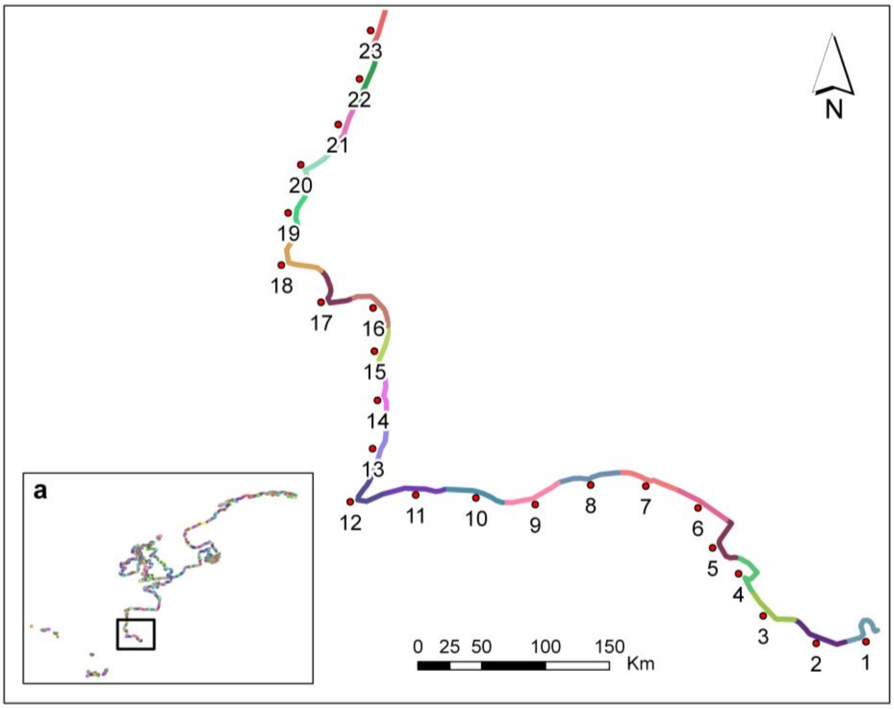


Figure 2.2. Detailed representation of the technical procedure followed for division in stretches along the southern part of the NEA (SW Iberian Peninsula), with indication of specific locations for reference points for quantification of physical variables.

2.2.2. Data

Taking into account the results obtained from preliminary analyses, which were carried out for the classification of this coastal area, five global variables and a total of 10 different indicators were selected: sea surface temperature (annual mean, maximum, minimum and standard deviation values), photosynthetically active radiation (annual mean, maximum and minimum values), salinity (annual mean), tidal range (annual mean) and significant wave height (annual mean). These variables fulfil the following criteria: (1) they are included in the WFD, (2) they are used in other regional classifications (e.g., Roff and Taylor, 2000; Connor et al., 2004; Lombard et al., 2004; Mount et al., 2007; Snelder et al., 2007), (3) they may be related to the geographical distribution of vegetation communities, (4) it is possible to obtain quantitative data at global scale within the study area and (5) indicators of the variables did not showed mutual influence (intercorrelation coefficient lower than 0.9).

For the study of the seasonal and interannual variability of those variables affecting the ecosystems, a combination of satellite and in situ data was used (Table 2.1). To estimate the variations of sea surface temperature (SST), remotely sensed Advanced Very High Resolution Radiometer (AVHRR) data from the Jet Propulsion Laboratory Physical Oceanography Distributed Active Archive Center (JPL PODAAC) were used. These data were processed in JPL within the NASA/NOAA AVHRR Oceans Pathfinder 5 project. The SST data series was composed by monthly estimates collected between 1982 and 2009. Only images from the ascending passes (night-time) were used in order to avoid daylight heating. During daytime, solar heating may lead to the formation of a very thin warm layer, particularly in regions with low wind speed. The data presented a spatial resolution of 4 km, which constitutes a compromise between the high spatial variability of the coastal regions and the data limitation due to cloud cover.

Estimates of Photosynthetically Active Radiation (PAR), derived from 9.3 km Sea-viewing Wide Field-of-view Sensor (SeaWIFS) Level 3 data, were provided by the NASA Goddard Space Flight Center, Distributed Active Archive Center. The data used is daily integrated, which takes into account the number of daylight hours and cloud coverage.

The exposure to wave action was obtained from the significant wave height records of five different satellite missions: TOPEX, TOPEX 2, Jason, Envisat, and Geosat Follow-On (GFO). The Atlantic basin was divided into a 1° x 1.5° grid (degrees latitude by degrees longitude), seeking a compromise between a representative number of data per cell and the highest spatial resolution. The tidal range was calculated from harmonic analysis computed using sea level observations of the TOPEX/Poseidon satellite altimetry.

Finally, in situ salinity values were used in this study due to the lack of long temporal series of remotely sensed data. Vertical profiles of water salinity measurements were provided by the "World Ocean Database 2009" (WOD) of the National Oceanic and Atmospheric Administration (NOAA)-NESDIS National Oceanographic Data Center (NODC) (Boyer et al., 2006). The procedures for data quality control and data fusion are described at the address: ftp://ftp.nodc.noaa.gov/pub/WOA09/DOC/woa09_vol2_text.pdf. The salinity profiles used in this study were acquired between 1990 and 2009, and only data within the 0-10 m layer were considered.

Table 2.1. Source and data series characteristics for each of the five variables selected (see text for the full name of acronyms).

Variables	Source	Data series		
		Period	Temporal resolution	Spatial resolution
SST	AVHRR Pathfinder v.5.0. project	1981-2009	Monthly average	4 km
PAR	SeaWiFS sensor	1997-2009	Monthly average	9.28 km
Wave height	TOPEX, TOPEX 2, Jason, Envisat, and GFO missions	1992-2009	Monthly average	1° x 1.5°
Tidal range	TOPEX/Poseidon mission	2007-2008	Minute	7 km
Salinity	NODC (NOAA data center)	1900-2010	*	*

* Random data distribution

According to the different spatial resolution of each data series (Table 2.1), SST, PAR and tidal range variables were obtained from the nearest point with satellite information to the reference points (cf. Figure 2.2). On the other hand, wave height and salinity were estimated as the average of all data points within a circle of 0.5 km radius around the reference points. This method avoids problems due to the sparse available data of these two variables.

2.2.3. Classification procedure

Following the procedure shown in Figure 2.1, two different steps were carried out for the establishment of the physical classification. First, a classification into broad geographic regions was developed, taking into account only SST (mean, maximum, minimum and standard deviation) and PAR (mean, maximum and minimum). These large regions ("biotypes" hereinafter) were obtained by hierarchical agglomerative clustering with complete linkage as the amalgamation rule, being this a suitable method to look for discontinuities in data (Legendre and Legendre, 1998). Previously, data series were normalised and used to construct a similarity matrix using Euclidean distances, since this is the appropriate distance measure for physico-chemical variables. These analyses were carried out using STATISTICA v.6.0.

A second step in the classification was accomplished in order to recognize and summarize the variability of environmental conditions within each biotype (i.e., subtypological variants). For this task the whole set of selected variables (SST, PAR, salinity, tidal range and significant wave height) was used to develop a cluster analysis similar to that of the first step. This hierarchical approach of further clustering within individual clusters is effective if a more extensively divided classification is desired (Buddemeier et al., 2008). In order to give more weight to temperature in the final classification, three SST indicators were included (average, maximum and minimum), but only the average of the other four variables.

Finally, in order to make a preliminary analysis of the suitability of the subtypological variants identified, these have been compared with coastal zones previously established by Member States (MS) in their national classification systems (Moy et al., 2003; Roger et al., 2003; Bettencourt et al., 2004; Spanish Environmental Ministry, 2008; Leonardsson et al., 2009; Ministry of Housing, Spatial Planning and Environment, 2009; Ministère, 2010; NLWKN, 2010).

The indicator used was the percentage of stretches integrated in each coastal zone at the national level that were also included in the same subtypological variant. In case more than one national type existed for each coastal stretch, the closest to the coast and/or with rocky substrate was selected. The global value for each MS was calculated as the average of “agreement” for the different estimated national types, according to the weighted length (number of stretches) of coast cover by each type.

2.3. Results

2.3.1. Data series

The basic information underlying classifications of the coastal area is the geographic distribution of each individual variable. A representation of data series, corresponding to the average of each variable divided into five equal interval classes can be observed in Figure 2.3. Sea surface temperature (Figure 2.3a) presented values between 5 and 21 °C, progressively increasing from North to South. Waters along the English Channel (extending southward into France), Southern Ireland and a small area in the northwest of the Iberian Peninsula showed medium SST values. Radiation followed the same trend (Figure 2.3b), except in the Skagerrak and Kattegat zones, where PAR was slightly higher.

On the other hand, as shown in Figure 2.3c the average wave height was maximum (around 3 m) in the West of Ireland, Northwest England and localized points in Norway and the Iberian Peninsula. All these coastal areas are very exposed to the Atlantic Ocean with a long fetch which permits the development of large waves. On the other hand, the Kattegat Strait coasts experience minimum wave conditions (around 0.5 m) due to the clear protected nature of this area. At the same time, the English Channel zone exhibited a high tidal range, typical of the restricted coastal configuration and shallow-water regions (Figure 2.3d). Finally, salinity did not change very much throughout the study area, except in the Kattegat and Skagerrak coasts, a transition area between the brackish Baltic Sea and the saline North Sea (Figure 2.3e).

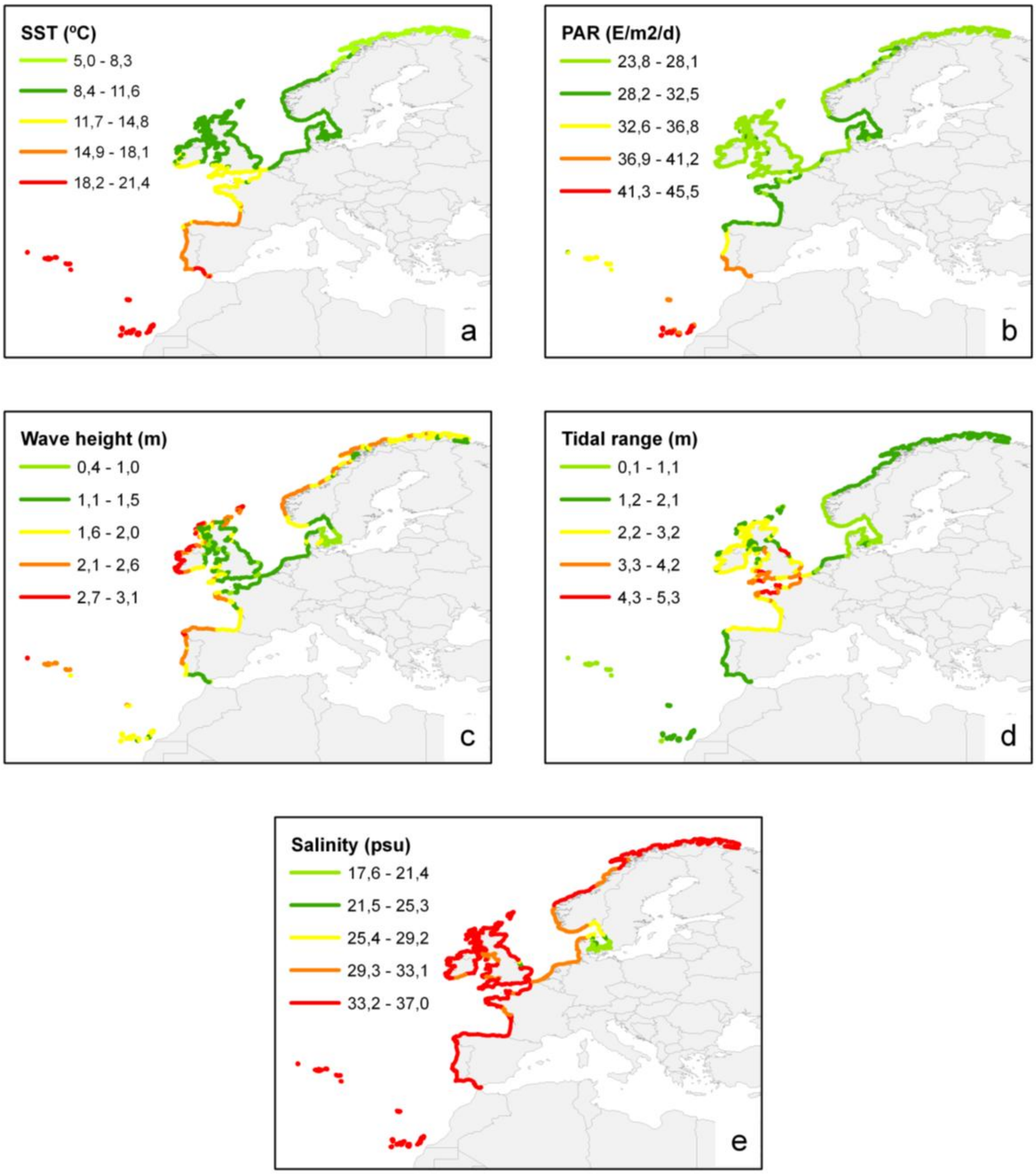


Figure 2.3. Spatial distribution maps of average values for physical variables along the NEA intercalibration region, using a five levels equal interval. From top left: (a) SST (°C), (b) PAR (E m^2 d^{-1}), (c) wave height (m), (d) tidal range (m) and (e) salinity (psu).

2.3.2. Physical classification

NEA coastal waters were classified in biotypes taking into account the results of the cluster analysis. Depending on the cut-off Euclidean distance considered (Figure 2.4, top), several classification schemes, including an increasing number of theoretical biotypes, could be obtained, as indicated in Figure 2.4(a-f). Taking into account the first threshold (linkage distance of 9.6) established in the cluster, a first general division was made in Brittany (France), distinguishing between a southern warm region (A) and a northern cold region (B) (Figure 2.4a). The second threshold (linkage distance of 7, Figure 2.4b) defined the difference between Canary Islands and Madeira (A1) and the rest of the southern region (A2). These islands present very specific conditions that make them a singular group (high SST and PAR, 20 °C and 42 $Em^{-2}day^{-1}$ on average, respectively). Furthermore, this group was characterized by a very low value of SST standard deviation (1.7 °C).

The next two subgroups refer to the northern area. The first one (Euclidean distance 4.8) subdivided group B into B1, Southern North Sea and the area of influence of the Baltic Sea, and B2, including the rest of the northern region (Figure 2.4c). A further division (Figure 2.4d, cut-off Euclidean distance of 4.64) distinguished the coastal region closer to the Arctic (B22, Trøndelag, and Northern Norway regions) with average SST ca. 11 °C, from the rest, the English Channel and the Northern area of the Bay of Biscay, Ireland, United Kingdom and Western Norway.

The final two divisions established from the cluster were related with much more specific gradients at a national scale. First (Figure 2.4e), the southern part of the Iberian Peninsula and the Azores were segregated from the group A2. Secondly, according to regional differences in temperature, with a cut-off Euclidean distance of 3.8 seven subgroups are obtained (Figure 2.4f).

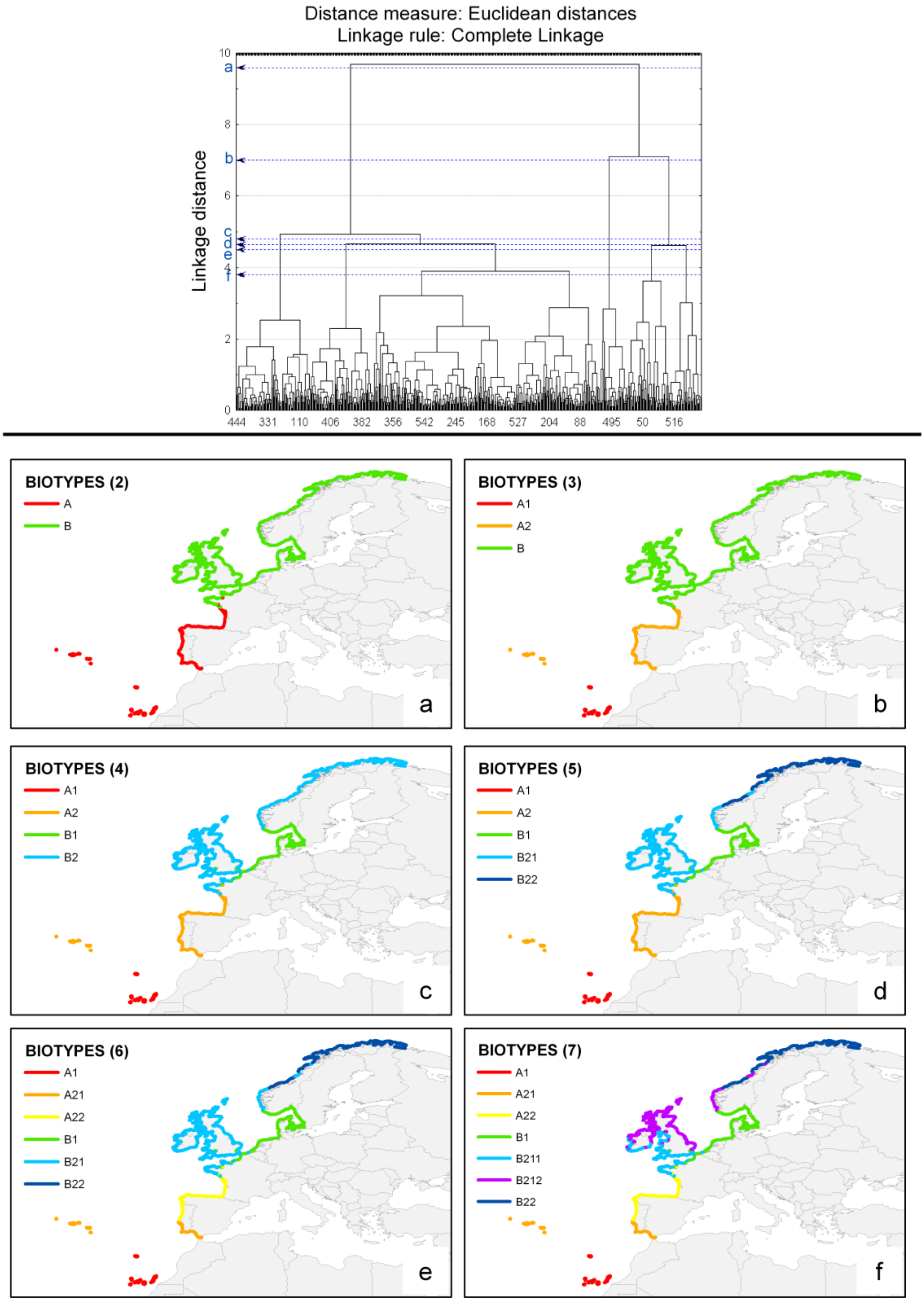


Figure 2.4. Results of the cluster analysis based on physical characterisation of coastal stretches throughout the NEA region (thresholds refer to cut-off Euclidean distances used for segregation of groups in figures a-f). Bottom: Groups obtained (biotypes) along the NEA region for different statistical thresholds: (a) 9.6 (2 biotypes), (b) 7 (3 biotypes), (c) 4.8 (4 biotypes), (d) 4.64 (5 biotypes), (e) 4.5 (6 biotypes) and (f) 3.8 (7 biotypes).

From these classification schemes a preliminary agreement on the suitability of five different biotypes (Figure 2.4d) within the NE Atlantic region was considered in this study (cf. Discussion). Thus, the results from the second step of physical classification can be observed in Figure 2.5. The five groups obtained with a cut-off Euclidean distance of 4.64 have been reclassified in order to identify potential subtypological variants within each. In this analysis a large variability is observed originating from the recognition of different environmental coastal conditions within each biotype.

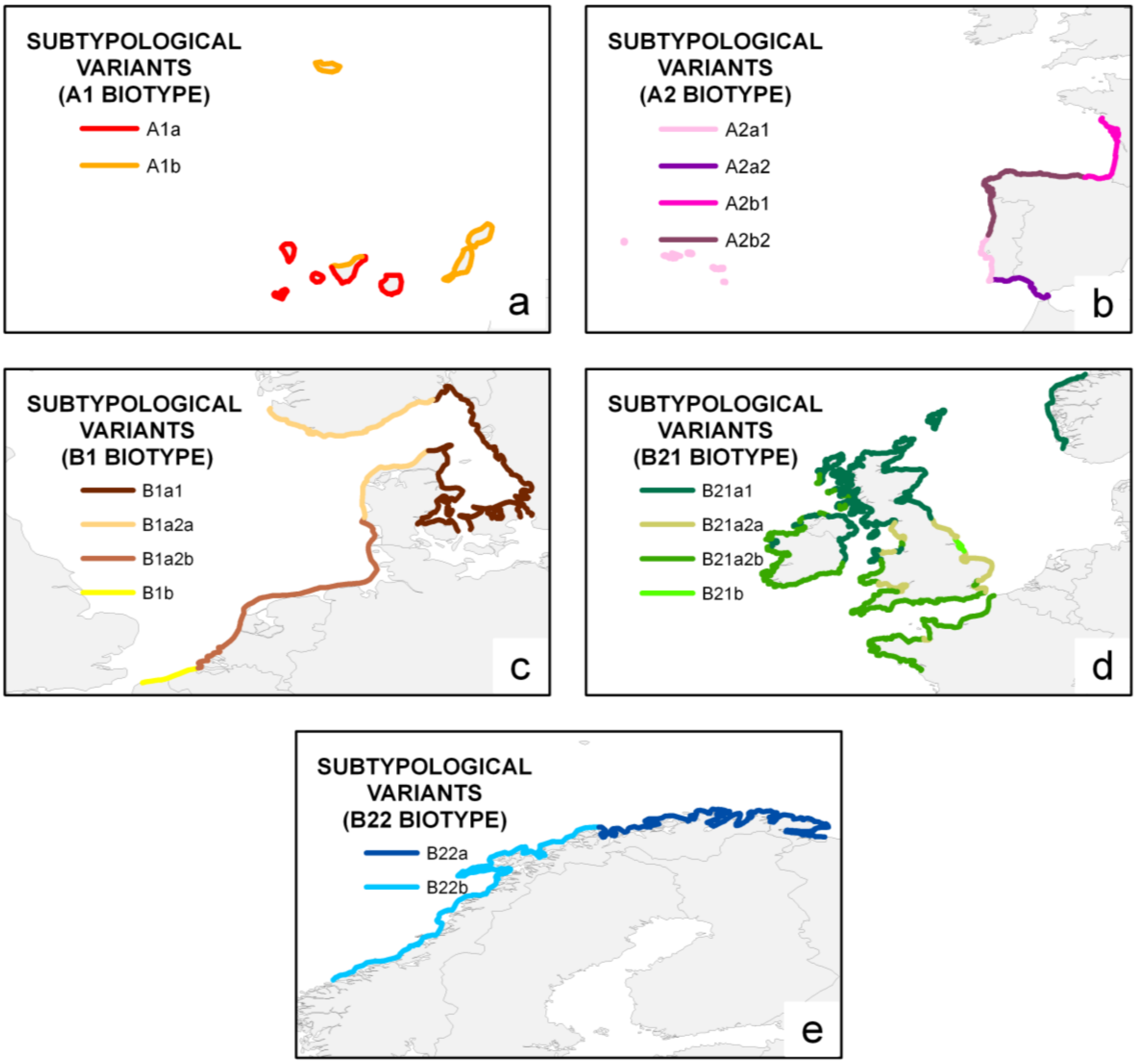


Figure 2.5. Results of cluster analysis for the second physical classification. From top left: (a) A1 biotype two subtypological variants), (b) A2 biotype (four subtypological variants), (c) B1 biotype (four subtypological variants), (d) B21 biotype (four subtypological variants), and (e) B22 biotype (two subtypological variants).

The boreal areas (A1 and B22) seemed to be those with less intravariability, especially the small region of Canary Islands and Madeira (Figure 2.5a). In the case of Norway, the theoretical subtypological variants were marked by latitude (Figure 2.5e). The other three biotypes considered (A2, B1 and B21) showed higher variability. As for Norway, the Iberian Peninsula (A2) was marked by latitude, following the gradient of SST (Figure 2.5b). However, in the case of group B1 (Figure 2.5c) a greater variability occurred along the salinity gradient influenced by proximity to the Baltic Sea. Finally, the highest variability was observed in the UK, Ireland and English Channel area (Figure 2.5d), in agreement with the complex coastal configuration of those islands (exposure conditions, tidal range, etc).

The comparison between theoretical subtypological variants and national types is shown in Table 2.2. For all MS the total agreement was higher than 70%. The higher “pondered agreement” occurred in the cases Germany, Sweden and Portugal. In addition, in the case of Portugal each national type corresponded almost perfectly to each potential subtypological variant. The lower agreement was found in UK, where two national types match only with a half of the potential subtypological variants.

Table 2.2. Comparison between national types and potential subtypological variants.

MS	National Type	Number of stretches	Subtypological variant	Percentage of common stretches	Pondered agreement
Spain*	12	9	A2a2	66.7 %	90.6 %
	13	6	A2b2	100 %	
	14	4	A2b2	100 %	
	15	5	A2b2	100 %	
	17	6	A2b2	100 %	
	20	2	A2a2	100 %	
Portugal	A5	7	A2b2	85.7 %	94.7 %
	A6	9	A2a1	100 %	
	A7	3	A2a2	100 %	
France*	C1	24	B21a2b	70.8 %	82 %
	C6	8	A2b1	100 %	
	C9	3	B21a2b	66.7 %	
	C11	3	B21a2b	100 %	
	C14	6	B21a2b	100 %	
	C15	3	B21a2b	100 %	
	C17	3	B21a2b	66.7 %	
UK*	cw1	75	B21a1	77.3 %	71.7 %
	cw2	14	B21a2b	78.6 %	
	cw4	24	B21a2a	50 %	
	cw5	58	B21a1	72.4 %	
	cw6	4	B21a	50 %	
	cw8	2	B21a1	100 %	
Ireland*	cw2	29	B21a2b	86.2 %	79.2 %
	cw5	18	B21a2b	66.7 %	
	cw8	1	B21a2b	100 %	
Germany	N1	2	B1a2b	100 %	100 %
	N2	2	B1a2b	100 %	
	N3	2	B1a2b	100 %	
	N4	2	B1a2b	100 %	
	N5	1	B1a2b	100 %	
Denmark	OW2	8	B1a1	100 %	88.9 %
	OW4	10	B1a2a	80 %	
Sweden	3	4	B1a1	100 %	100 %
	4	4	B1a1	100 %	
	5	4	B1a1	100 %	
	6	1	B1a1	100 %	
Norway**	SK1	10	B1a2a	70 %	88.4 %
	NS1	14	B21a1	78.6 %	
	NH1	45	B22a	86.7 %	
	BA1	34	B22a	100 %	

* National types considered the closest to the coast and/or these with rocky substrate.

** Including only the exposed coast.

2.4. Discussion

Results presented in this work are taken to demonstrate the global suitability of the methodological approach applied for the objective definition of possible biotypes along the NEA region with homogeneous and standardized available data. This approach intends to remove any ambiguity in the use of subjective classification schemes, ensuring that results are reliable and provide a sound foundation for ascertaining statistically different biotypes.

In spite of this global agreement with the main goal of this paper, several questions, both methodological and conceptual, arise for debate. Some of the most likely reservations on technical terms refer to obtaining quality information throughout a large biogeographic area (i.e., the NE Atlantic) with the sufficient precision for detecting the most significant regional singularities.

A crucial aspect in the development of a classification system based on physical descriptors is to quantify those variables in a homogeneous way and with an adequate level of accuracy. Nowadays, the advance produced in generating oceanographic and meteorological data from satellite sensors provides a tool of enormous potential for the objectives raised in this study. In this sense, it should be noted that the data series obtained demonstrated that this is a valid method for quantifying the selected variables, reflecting the same patterns as those described by other authors, regarding for instance global tidal range and wave height (Briggs et al., 1997), Atlantic sea temperatures (van den Hoek, 1982a1982b), the sea surface temperatures along the Iberian Peninsula (Fraga, 1981) and salinity gradient in the Kattegat and Skagerrak areas (Jakobsen, 1997). In addition, the selected satellite sensors (AVHRR Pathfinder, TOPEX/Poseidon, SeaWIFS, etc.) have been widely used providing validated and reliable data (Yu and Emery, 1996; Smith et al., 1998; Hooker and McClain, 2000; Li et al., 2001)

In the same way, this similarity between the present results and previously described patterns along the same study area confirms that the procedure used to quantify variables 5 km away from coast was appropriated for analyzing the variability of the main coastal physical features at the scale as wide as the NEA GIG. If the location of reference points (where the variables were estimated) had been situated closer to the coastline, it would not have been possible to obtain continuous and homogenized information throughout the NEA coast. Otherwise, the measurement of variables in points situated further than 5 km offshore would have shown oceanographic characteristics instead of coastal ones. Moreover, data information thus obtained could be used for multiple analyses of the area (classification of other systems related to the marine environment as transitional waters, prediction of potential habitats for a wide range of flora and fauna, etc.).

From a conceptual point of view, the identification of significant differences in environmental conditions is a problem of the working scale and the specific objective of the study. The eastern Atlantic coasts of Europe may be considered either as a whole aquatic system or as a complex mosaic of regional seas (e.g., WFD), whose borders are not real but either administratively defined or scientifically justified. For intercalibration purposes, a classification system seems to be required in order to improve the quality of comparisons between assessment results of the vegetation quality element. So the methodological proposal applied in this study is an objective way to carry out those objectives.

In regard to the first physical classification, the procedure reflects different divisions of the region depending on the significance level (linkage distance) applied to the cluster analysis. This iterative procedure for the selection of a classification scheme generates a sufficient variety of results that may accomplish the specific requirements for the decisions of national experts on the more suitable proposals of biotypes. That was one of the main strengths of the statistical methodology followed in this study, taking into account that these biotypes are integrated in a continuous environment, whose limits must be better considered as gradient zones. On the other hand, main weakness of this method may be related to the selection and weighted of variables for cluster analyses.

In this sense, considering five biotypes within the NEA intercalibration region (with a “cut-off” Euclidean distance of 4.64, Figure 4d) seemed to be the most adequate for the intercalibration purpose. Therefore, these biotypes could be used as higher affinity areas, establishing groups inside which vegetation communities can be compared, and intercalibration performed in a safer way. However, it should be considered that as a flexible proposal that must take into account possible regional or local singularities. Specific analyses of possible particular characteristics are always needed (e.g., salinity in Skagerrak and Kattegat areas).

This classification on five biotypes presents a study scale equivalent to other previously developed schemes that include the European coast, as OSPAR regions, the Water Framework Directive ecoregions for transitional and coastal waters, LME ecological regions, the Marine Strategy Framework Directive subregions or the NEA coastal water types for the intercalibration exercise. In fact, there is no objective information (data) that explains or justifies the procedure carried out for the establishment of those classifications, as has been evidenced in the work of the Geographical Intercalibration Groups. For example, in the NEA coastal water types, the division of the type 1/26 in five subtypes (a-e) for phytoplankton quality analyses was explained by the different influence of the upwelling, but without objective data that could put in evidence the divisions made (European Commission, 2009b). Hence, the approach used in this paper offers a considerable advance in this sense.

Anyway, some information should be in the technical base of those classification schemes since there are obvious cases of large areas that coincide with the quantitative results obtained in this study. Such is the case of those classifications that identify the physical singularity of the Norwegian Sea (northern part of Norway = biotype B22). On the other hand, the extension of continental Southern Region of OSPAR and MSFD (“Bay of Biscay and Iberian Coast”) is very similar to that of the A2 biotype, with a limit slightly further south in our case.

Following the debate on the conceptual meaning of the obtained biotypes and their geographical limits, the importance of the biological validation (Figure 2.1, steps 3 and 4) must be stressed as a basic support for the final interpretation of specific relationships between the actual distribution of aquatic communities and their physical environment. Furthermore, the implementation of “predictive tools” based on physical descriptors would improve the management capacity of these ecosystems. In this way, the spatial-temporal delimitations of gradient zones (e.g., establishment of the northern limits for the A2 biotype in the Brittany coast) or the justification for a more precise assignment of biotypes of certain coastal areas (e.g., Celtic and North Sea related areas from the UK or the Skagerrak area) should be further considered.

Another aspect that is necessary to rise in relation to the procedure proposed is the necessity or not to divide the physical classification in two steps in order to apply a sort of hierarchical classification (Figure 2.1). In this sense, previous trials showed how the use of all variables in a single classification analysis resulted in the aggregation of regions as diverse as Norway and the Iberian Peninsula in the same group. Moreover, hierarchical approaches have been long used to classify coastal areas, supporting the advantage of this type of technical procedures (e.g., Dethier, 1990; Connor et al., 2004; Davies et al., 2004; Madden et al., 2009)

Going into detail, confirming the distribution of biotypes as a gradient and the difficulty of establishing borders in a continuous environment, some coastal zones could be distinguished, where stretches of two different groups appear interspersed (see Figure 2.4d). For instance, that was the case of the coastal area between groups A2-B21 (Brittany in France) and B21-B1 (Nord-Pas-de-Calais in France and Belgium). The first gradient zone (A2-B21) could be attributed to the gradual change from a warm temperate region to a cold one (Dinter, 2001). This diffuse border is also marked by macroalgae distributions, with Brittany being the southern distributional limit for many northern species (OSPAR, 2010). On the other hand, the second gradient area (B21-B1) could be explained by the change in the average salinity registered in the area (Figure 2.3e). Therefore, it seems to be appropriated to justify the location of the boundaries between biotypes in a more flexible way.

The five biotypes proposed for the present WFD intercalibration exercise have been slightly homogenized according to MS expert knowledge to obtain continuous coastal sections (Figure 2.6). These continuous biotypes have been the ground for the development of the second physical classification. So, the objective of the second phase was not directed to the establishment of new subtypes but to recognize the coastal areas that may reflect the variability of environmental conditions within each biotype (subtypological variants). Such information is very useful for either the development of the WFD intercalibration exercise or of a further study on the appropriated adjustment of the current biotypes in some areas (e.g., Skagerrak and Kattegat zones). In this step of the classification it was necessary to employ the whole set of variables, demonstrated by the different distribution of subtypological variants inside each biotype, due to the variability caused by different environmental parameters (geomorphology of the coast on a broad scale, latitude related with temperature and radiation, salinity, etc.). Therefore, this variability is very important at the lower scale study (biotype), being more variable in those areas situated in the temperate region. An important aspect in the recognition of this variability (subtypological variants) is to compare how the global analysis performed in this work fits with the boundaries established by each MS for their coastal zone. Results of this basic analysis showed a generally good agreement between both approaches, regarding the integration of most of national types within only one of the subtypological variants established. However, such concordance depended very much on the scale of work at the national level and the specific criteria used for the classification. For instance, the agreement is higher in the coastal zones of Portugal than in UK. It could be due to coastline shape, as stated before. The shape allows the sheltered and exposed coasts to exist, and the approach here used may put in evidence homogeneity from regular coastlines. Countries where sheltered shores are not so frequently intercalated with exposed ones, found in national classifications a higher agreement with this one. Sheltered shores are less influenced by offshore environmental conditions (as used in this study) than more exposed ones. So, countries where the presence of sheltered shores is more frequent, is expected a higher disagreement between results from this work and national classifications. This way, it seems that the physical classification would be able to reflect the general variability of the system at the biotypes scale, although some national classification systems have gone further in this analysis.

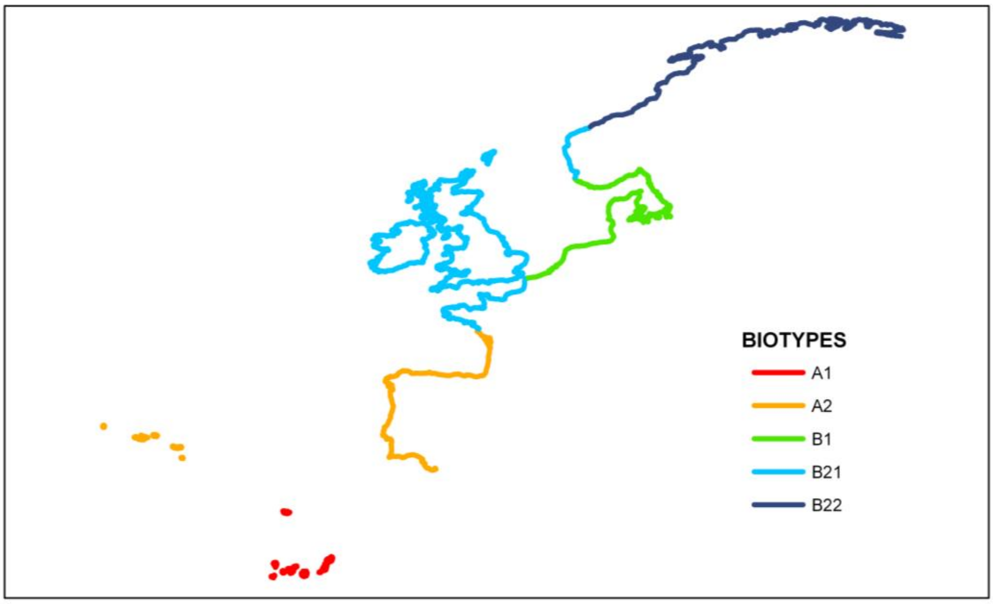


Figure 2.6. Biotypes proposed for intercalibration exercise within the NEA region.

In conclusion, the methodological approach proposed in this paper allows, firstly, to establish a classification system of the coast environment (biotypes) that is in agreement with the main goal previously described and, secondly, to recognize the variability associated with each of these biotypes. For this purpose, the quantification of variables by means of satellite sensors presently offers a useful approximation and promises a great future because of its unique viability dealing with global scale studies. Furthermore, according to other authors (Roff and Taylor, 2000) it is possible to assume that the proposed classification would be able to represent the distribution of marine species along the NE Atlantic region. However, after the theoretical verification of the physical classification system, it seems clear that its use as the basis to carry out an ecological typification of the study area requires a validation to establish its real ecological meaning. It is therefore necessary to know the relationship between the actual distributions of the different features of macroalgae communities along this huge region. The comparison of the groups obtained in the physical classification and the information of the populations colonizing coastal areas is very important, given that it would allow, first, to properly interpret and to identify potential habitats and species communities and, second, to establish the different reference conditions. This basic procedure constitutes part of the second phase presented in Figure 2.1, including the detection of the most representative macroalgal taxa along the study area, the selection of those which may define biogeographic differences and the validation with macroalgae distribution in order to check the ecological suitability. Due to the difficulties for the generation of homogeneous standardized data all along the NEA region, this study is treated in more detail in Chapter III.

Chapter III

Biological validation at European scale

Chapter III. Biological validation at European scale

This chapter is an edited version of the research article published in the journal Estuarine, Coastal and Shelf Science, vol. 147, pp. 103-112, by Ramos, E., Puente, A., Juanes, J.A., Neto, J.M., Pedersen, A., Bartsch, I. Scanlan, C., Wilkes, R., van den Bergh, E., Ar Gall, E., Melo, R. in 2014 with the title "Biological validation of physical coastal waters classification along the NE Atlantic region based on rocky macroalgae distribution".

Abstract

A methodology to classify rocky shores along the North East Atlantic (NEA) region was developed. Previously, biotypes and the variability of environmental conditions within these were recognized based on abiotic data. A biological validation was required in order to support the ecological meaning of the physical typologies obtained. A data base of intertidal macroalgae species occurring in the coastal area between Norway and the South Iberian Peninsula was generated. Semi-quantitative abundance data of the most representative macroalgal taxa were collected in three levels: common, rare or absent. Ordination and classification multivariate analyses revealed a clear latitudinal gradient in the distribution of macroalgae species resulting in two distinct groups: one northern and one southern group, separated at the coast of Brittany (France). In general, the results based on biological data coincided with the results based on physical characteristics. The ecological meaning of the coastal waters classification at a broad scale shown in this work demonstrates that it can be useful as a practical tool for conservation and management purposes.

3.1. Introduction

The emergence of a worldwide environmental management arose in the 1990s, showing the need of integrate pollution control and develop a coordinate ecosystem approach which combines natural and social sciences (Apitz et al., 2006). In Europe, after other proposals, this idea resulted in the European Water Framework Directive (WFD, Water Framework Directive 2000/60/EC), which involves the intercalibration (IC) of ecological assessment methods within four different Geographical Intercalibration Groups (GIGs). One of them is the North East Atlantic (NEA) region, which comprises the area from Northern Norway to the Canary Islands. Additionally to this first broad division, common IC types within GIGs are required in order to remove the effects of geographical differences before comparing assessment methods (European Commission, 2009b).

In spite of the number of classification approaches (e.g., Devilliers and Devilliers-Terschuren, 1996; Connor et al., 1997; Davies et al., 2004), there was not a harmonized and standardized classification methodology that can be generally used for management and conservation purposes. Taking this into account, a physical classification along the NEA coastal area was developed by Ramos et al. (2012). Thereby, suitable information was provided to justify the establishment of physically harmonized outer coastal zones for the potential distribution of macroalgae. The biotypes obtained were adopted for the IC of macroalgae dividing the common IC type NEA 1/26 into “NEA 1/26 A2” (Iberian Peninsula and Southern France) and “NEA 1/26 B21” (Northern France, Ireland, Norway and UK).

An important criterion in a classification system is an objective statistical demonstration which proves that the derived classification units are significantly similar or different, based on both environmental and biological characteristics (Valesini et al., 2010). However, this biological criterion is lacking in most of the existing coastal classifications and the establishment of suitable biotypes along the NEA intercalibration region is not yet finished. It is necessary to develop a second step as defined by Ramos et al. (2012): the detection of the most representative macroalgae taxa along the study area and the use of this macroalgae distribution in order to check the ecological suitability of the physical classification system. The strong correlation between macroalgae species and abiotic factors shows the utility of these variables as indicators of potential habitats for different communities and, consequently, for the establishment of coastal ecosystem classifications (Roff and Taylor, 2000). Therefore, detailed information about the spatial distribution of macroalgae is a fundamental issue, providing a way of testing the biological suitability of a physical classification.

A comprehensive single and standardized inventory all along the NEA region does not exist, which hampers an adequate approximation of intertidal macroalgae species distribution for marine management purposes. In addition, the stronger knowledge of species composition and biodiversity around this area is of utmost importance to maintain the long-term suitability of ecosystems, allowing a better evaluation of changing environmental conditions as global warming (Verfaillie et al., 2009).

Considering all these aspects, the development of a suitable ecological classification system is an important feature for different management actions. It will be useful in the implementation of different legislation, as well as for the general assessment of coastal ecosystems. The main goal of this work is the biological validation of the physical classification developed by Ramos et al. (2012). In addition, this work provides homogenous and standardized information about the biogeographical distribution of intertidal macroalgae species along NE Atlantic region, and characterizes common biotypes according to macroalgae data.

3.2. Methods

3.2.1. Study area

The study was undertaken from Norway to the southern Iberian Peninsula as delineated by the NEA region. Taking into account the intrinsic characteristics of the study area (i.e., the existence of intertidal rocky substratum that enables the development of seaweeds), the coast line of seven countries was included in the analyses (Portugal, Spain, France, Ireland, UK, Germany and Norway).

The physical classification carried out by Ramos et al. (2012) along this coastal area has been the basis of this work. In this paper authors developed a classification into broad geographic regions (biotypes). A1 biotype includes the Canary Islands and Madeira; A2 Iberian Peninsula, South France and the Azores; B1 the continental coast of the North Sea, including Helgoland island, Kattegat and Skagerrak areas until Rogaland (Norway); B21 the British Isles (the UK and Republic of Ireland), North France and the western coast of Norway; and, finally, the B22 biotype encompasses Trøndelag and Northern Norway regions. Then, a second step recognized the variability of environmental conditions within each biotype (subtypological variants). In the case of biotype B21, physical subdivisions have been slightly homogenized, some stretches of different subtypological variants were joined in order to obtain continuous coastal sections.

3.2.2. Macroalgae data

In order to match the biological validation as closely as possible to the previous physical system a location was selected every 40 km among the total available sites with macroalgae information (i.e., rocky intertidal areas), following the approach established by Ramos et al. (2012). This selection was made by Member State (MS) experts among sites previously used for IC exercise, with biological data based on field work available, taking into account also that each one was representative of the nearby area. This way, 117 locations were established in the study area as shown in Figure 3.1.

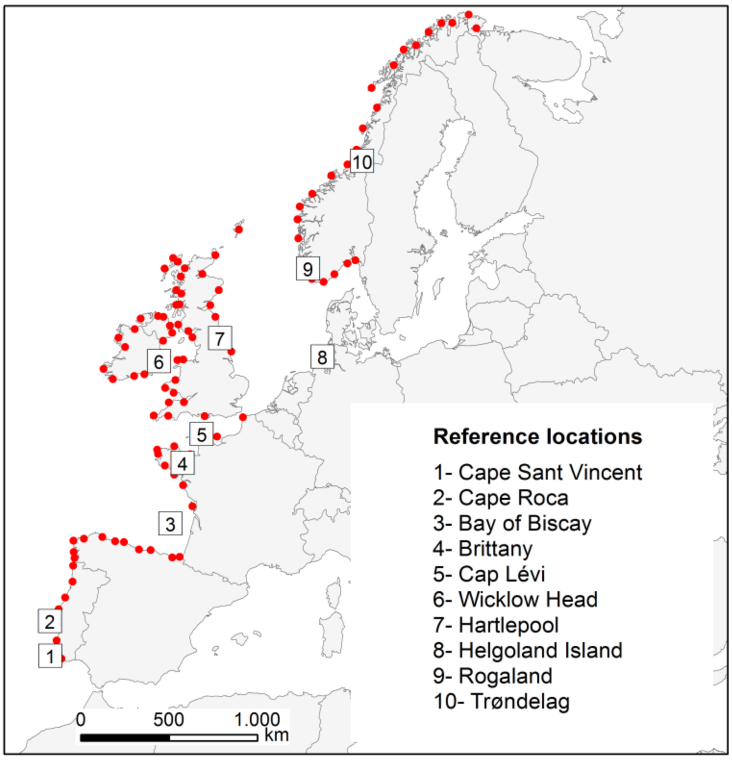


Figure 3.1. Spatial distribution of biological data location along NEA coast. Numbers correspond to reference locations.

With the purpose of generating a homogenous and standardized biological data base, the most suitable macroalgae species that may represent the NEA intertidal rocky shore were previously established by MS experts. This selection was based on other similar species lists already developed (c.f. Guinda et al., 2012), finally including the macroalgae species considered conspicuous at least for one MS. A common data base was elaborated with biological data classified as: species absent, rare (dispersed specimens with a low frequency of appearance) or common (specimens forming patches or belts) in each location. Experts of each MS established these ranges taking into account the original quantitative data obtained by field surveys in the different regions and provided the biological information: Portugal (Araújo et al., 2009; Gaspar et al., 2012), Spain (NEA GIG, 2013), France (Ar Gall and Le Duff, 2012), Ireland (NEA GIG, 2013), UK (NEA GIG, 2013), Germany (Bartsch and Kuhlenkamp, 2000; Bartsch and Tittley, 2004) and Norway (Brattegard and Holthe, 1997). Field work was carried out during spring and summer periods from 2007 to 2012.

Macroalgae data were compiled using the same species matrix and the same cover code, with the purpose of avoiding differences in taxonomic identification between working groups. Data were standardised, by combining the following species in the corresponding genus: *Ceramium ciliatum, Ceramium circinatum, Ceramium echionotum, Ceramium gaditanum, Ceramium pallidum, Ceramium shuttleworthianum, Ceramium tenuicorne* and *Ceramium virgatum* were subsumed in *Ceramium* spp.; *Cladophora albida, Cladophora dalmatica, Cladophora hutchinsiae, Cladophora laetevirens, Cladophora lehmanniana, Cladophora pellucida, Cladophora rupestris* and *Cladophora sericea* in *Cladophora* spp.*; Corallina officinalis* and *Ellisolandia elongata* in *Corallina/Ellisolandia; Jania rubens* and *Jania squamata* in *Jania* spp.*; Phyllophora crispa, Phyllophora heredia* and *Phyllophora pseudoceranoides* in *Phyllophora* spp.*;* and *Polysiphonia elongata, Polysiphonia foetidissima, Polysiphonia fucoides, Polysiphonia nigra* and *Polysiphonia stricta* in *Polysiphonia* spp. In addition, species presented just in one or two locations were removed in order to reduce noise in the final results (*Acrosiphonia spp., Sphaerococcus coronopifolius, Taonia atomaria* and *Valonia utricularis*). The resulting data set comprised 117 taxa.

3.2.3. Biological validation procedure

Multivariate analyses were performed at two levels, biotypes and subtypological variants, in order to test and validate the general agreement between intertidal macroalgae communities and the physical classification. For this purpose, a biological matrix was created based on the information previously collected that comprises absent (0) rare (1) and common (2) species distribution. All statistical analyses were carried out using the package PRIMER-E (v.6 + PERMANOVA).

Firstly, the suitability of biotypes was tested. Untransformed data has been used, taking into account that a semi-quantitative scale of abundance is roughly equivalent to the performance of fourth root transformation (Clarke and Warwick, 2001; Puente and Juanes, 2008). A cluster analysis, using Bray-Curtis similarity coefficient, was carried out to identify groups according to macroalgae distribution and to relate these groups with physical biotypes. Taxa making the greatest contribution to the differences between biological groups were detected through SIMPER analysis. In addition, taking into account that it is difficult to establish borders in a continuous environment, a multi-dimensional scaling MDS analysis was performed to identify gradients and patterns in the seaweed taxa distribution. Locations were represented in the graph according to typical geographic regions to help in its interpretation. Vectors defining correlations between macroalgae and physical variables, which data was obtained from Ramos et al. (2012), were analyzed in order to establish connections between them. Lastly, a permutational multivariate analysis of variance (PERMANOVA, Anderson, 2001) was performed to detect significant differences in the taxa composition among different physical groups obtained in the previously mentioned analysis. Biotype was the fixed factor considered and each term in the analysis was tested using 9999 permutations. Significant terms and interactions were investigated using *a posteriori* pairwise comparisons with the PERMANOVA-t statistics.

Afterwards, macroalgae data within biotypes were analyzed (subtypological variants level). For this purpose, the biological database was divided into four different matrices according to biotypes. Essentially the same multivariate analyses as those previously carried out for biotypes were developed. Nevertheless, PERMANOVA analysis was adapted, *P*-values were obtained using a Monte Carlo random sample from the asymptotic permutation distribution, since in some cases the number of possible permutations was low.

3.2.4. Biotypes biological characterisation

Once the biological suitability of physical groups had been tested, biotypes were characterized according to macroalgae data. The number of taxa present in each biotype was calculated, as well as the total number and percentage of Rhodophyta, Ochrophyta and Chlorophyta. In addition, a SIMPER analysis was carried out in order to identify the most representative taxa explaining similarities among biotypes.

3.3. Results

3.3.1. Macroalgae data

The list of the most suitable macroalgae taxa that may represent the NEA intertidal rocky shore are given in Table 3.1.

Table 3.1. Taxa list of characteristic intertidal rocky shore macroalgae along NEA coast.

Chlorophyta

Blidingia spp.
Bryopsis plumosa
Chaetomorpha linum
Cladophora spp.
Codium adhaerens
Codium tomentosum
Codium spp.*
Derbesia spp.
Monostroma grevillei
Prasiola stipitata
Rosenvingiella spp.
Spongomorpha arcta
Ulothrix spp.
Ulva spp.
Urospora spp.

Ochrophyta

Alaria esculenta
Ascophyllum nodosum
Asperococcus fistulosus
Bifurcaria bifurcata
Chorda filum
Chordaria flagelliformis
Cladostephus spongiosus
Colpomenia spp.
Cystoseira baccata
Cystoseira tamariscifolia
Desmarestia aculeata
Dictyopteris polypodioides
Dictyosiphon foeniculaceus
Dictyota dichotoma
Ectocarpus spp.
Fucus evanescens
Fucus serratus
Fucus spiralis
Fucus vesiculosus
Halidrys siliquosa
Halopteris filicina
Himanthalia elongata
Laminaria digitata
Laminaria hyperborea
Leathesia spp.
Padina pavonica
Pelvetia canaliculata
Petalonia fascia
Petalonia zosterifolia
Saccharina latissima
Saccorhiza polyschides
Sargassum muticum
Scytosiphon lomentaria
Stypocaulon scoparium

Rhodophyta

Aglaothamnion/Callithamnion /Antithamnion
Ahnfeltia plicata
Asparagopsis armata
Boergeseniella thuyoides
Bonnemaisonia hamifera
Brongniartella byssoides
Catenella caespitosa
Caulacanthus ustulatus
Ceramium spp.
Chondracanthus acicularis
Chondracanthus teedei
Chondria coerulescens
Chondrus crispus
Chylocladia verticillata
Corallina/Ellisolandia
Corallinaceae-crusts
Cryptopleura ramosa
Cystoclonium purpureum
Delesseria sanguinea
Dilsea carnosa
Dumontia contorta
Furcellaria lumbricalis
Gastroclonium ovatum
Gelidium corneum
Gelidium pulchellum
Gelidium pusillum
Gelidium spp.*
Gelidium spinosum
Gigartina pistillata
Gracilaria gracilis
Gymnogongrus spp.
Halopithys incurva
Halurus equisetifolius
Heterosiphonia plumosa
Hildenbrandia rubra
Hypoglossum hypoglossoides
Jania spp.
Laurencia obtusa
Lomentaria articulata
Mastocarpus stellatus
Membranoptera alata
Nemalion helminthoides
Odonthalia dentata
Osmundea hybrida
Osmundea pinnatifida
Palmaria palmata
Peyssonnelia spp.
Phycodrys rubens
Phyllophora spp.
Plocamium cartilagineum
Plumaria plumosa
Polyides rotunda
Polysiphonia spp.
Porphyra linearis
Porphyra purpurea
Porphyra spp.*
Porphyra umbilicalis
Pterocladiella capillacea
Pterosiphonia complanata
Pterosiphonia spp.*
Pyropia leucosticta
Ptilota gunneri
Rhodochorton purpureum
Rhodomela confervoides
Rhodothamniella floridula
Rhodymenia spp.
Vertebrata lanosa

*Other than the species of the same genus already mentioned in the list.

The macroalgae taxa obtained consisted of 68 Rhodophyta, 34 Ochrophyta and 15 Chlorophyta. The intertidal macroalgae generally throughout the study area were *Corallina/Ellisolandia* and Corallinaceae-crusts and the opportunists *Ceramium* spp. and

Ulva spp. Apart from these, the most frequently present taxa were, in this order: *Chondrus crispus, Mastocarpus stellatus, Cladophora* spp.*, Fucus serratus, Fucus vesiculosus, Fucus spiralis, Cladostephus spongiosus* and *Dictyota dichotoma.* The locations that presented the highest number of macroalgae taxa were located in South Norway (85). By contrast, the lowest number of taxa was found in France, i.e., in Cap Lévi with 14 taxa.

3.3.2. Biotypes biological validation

The aggregation analysis tested and validated the general agreement between macroalgae distribution and biotypes, though there were some exceptions. As can be observed from Figure 3.2a, the cluster discriminated between two main groups: “A” and “B” (Bray-Curtis similarity distance of 10), corresponding to the first division in the physical classification, biotypes A2 and B1, B21 and B22 respectively. The broad division using biological data was established around Brittany (France), as was obtained in the physical classification. Taxa with the higher contribution to this dissimilarity were, in this order, *Fucus serratus, Laminaria digitata, Caulacanthus ustulatus, Ascophyllum nodosum, Fucus spiralis, Palmaria palmata, Pelvetia canaliculata* and *Fucus vesiculosus*. Thus, these species were responsible for the latitudinal gradient towards north.

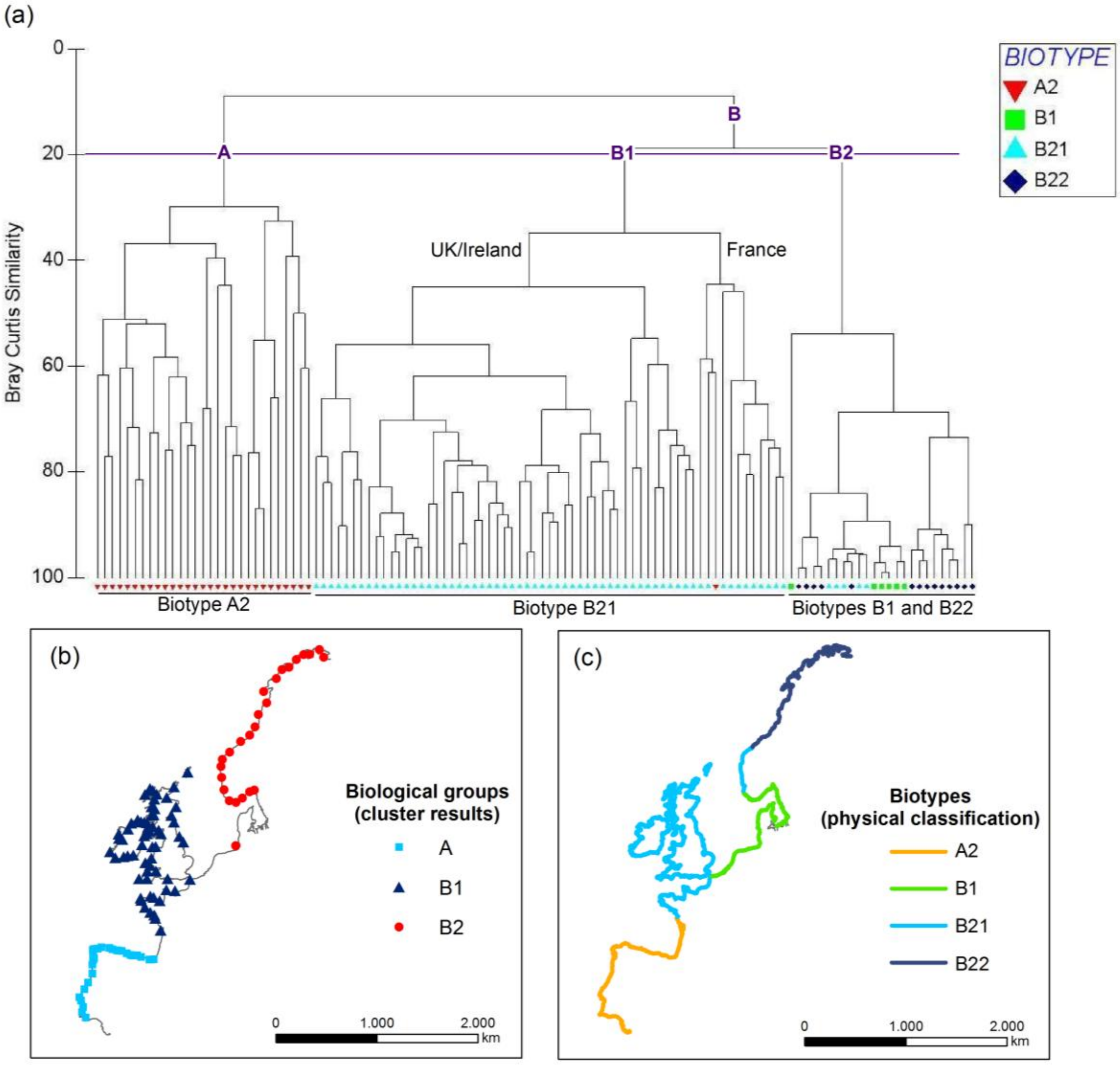


Figure 3.2. (a) Dendrogram resulting from the classification analysis based on macroalgae taxa data. Corresponding physical biotypes (A2, B1, B21 and B22) are indicated. (b) Representation of biological groups along the NEA region (cut-off Bray-Curtis similarity distance of 20). (c) Representation of biotypes obtained by the physical classification. Source: Ramos et al. (2012).

The second threshold (cut-off Bray-Curtis similarity of 20, Figure 3.2) defined the difference between UK, Ireland and France (biotype B21) and Helgoland and Norway (mostly biotypes B1 and B22). Taxa with a higher contribution to this second division were *Porphyra* spp., *Chordaria flagelliformis, Urospora* spp., *Porphyra purpurea, Pterosiphonia* spp., *Ptilota gunneri, Desmarestia aculeata* and *Delesseria sanguinea.* Inside the group corresponding to biotype B21 (biological group B1), locations were divided into two groups at a relatively low level of similarity, France on one side and UK and Ireland on the other. Lastly, within the second group (biological group B2) there was a split between Helgoland and the rest of the locations. The remaining sites in this group were separated into two other small groups, Northern Norway (biotype B22) and Southern Norway (biotypes B1, B22 and a very small portion of B21).

The representation of sample locations in the MDS graph was made according to countries or to geographical regions inside these if necessary in order to allow an adequate visualization of the results (Figure 3.3). The ordination analysis showed a clear gradient north-south and confirmed the biological differences between biotypes previously established in the physical classification. Norwegian points were located on the upper part of the MDS graph while Iberian Peninsula ones were located on the bottom. Also, French locations were situated between biotype A2 (Iberian Peninsula and south France) and biotype B21 (Ireland and UK islands), which showed the transitional character of this area. The strong latitudinal gradient was clearly observed between countries, but also inside these, as can be observed along UK and Norway. According to vectors defining correlations (not shown) this latitudinal gradient was mainly caused by the orders Fucales and Laminariales, brown algae that dominate the northern area. Among these there were *Fucus serratus, Laminaria digitata, Ascophyllum nodosum, Fucus vesiculosus, Fucus spiralis* and *Saccharina latissima.* By contrast, macroalgae that showed a higher presence in the southern area were mostly Rhodophytes (*Caulacanthus ustulatus, Chondracanthus acicularis, Asparagopsis armata, Chondria coerulescens, Gymnogongrus* spp.*, Gelidium pulchelum, Chondracanthus teedei* and *Boergeseniella thuyoides*) and also an Ochrophyta (*Bifurcaria bifurcata).* In relation to physical variables, this gradient was related with maximum, minimum and average SST and maximum and average PAR. As expected, all these variables were higher towards the south.

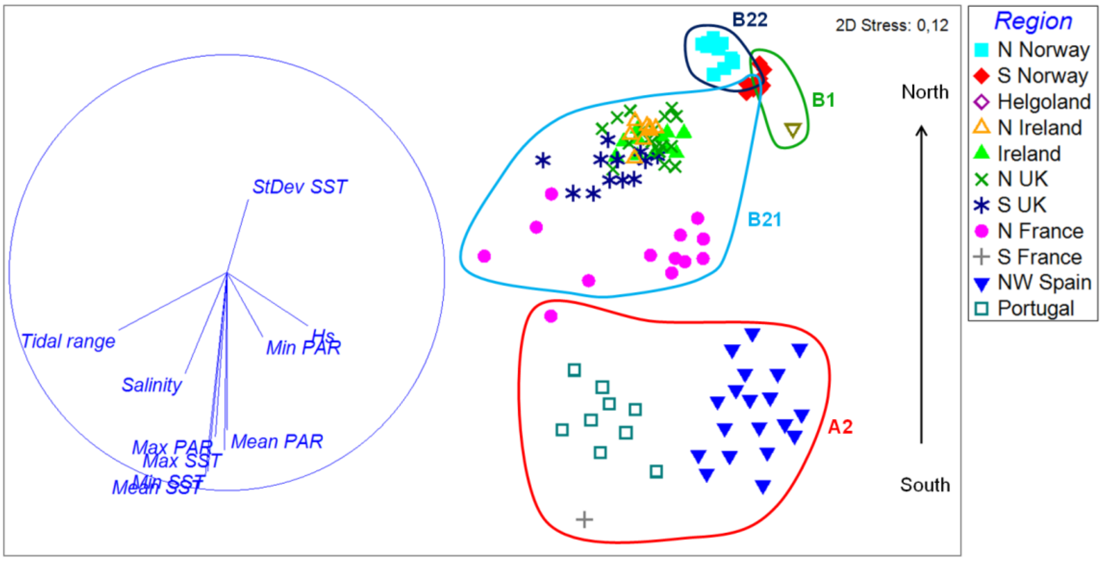


Figure 3.3. MDS analysis distribution of the different sampling locations according to geographical regions. Vectors define correlations between macroalgae and physical variables: annual mean (Mean SST), maximum (Max SST), minimum (Min SST) and standard deviation (StDev SST) sea surface temperature; annual mean (Mean PAR), maximum (Max PAR) and minimum (Min PAR) photosynthetically active radiation; annual mean tidal range (Tidal range); and significant wave height (Hs).

The group on the bottom of the MDS graph (south area) presented high variability, with Iberian Peninsula locations spread along the horizontal axis. In addition, with a more detailed analysis (not shown here) it can be seen that French and Spanish locations located along the Bay of Biscay were situated below the rest of the Iberian Peninsula coast. This organization showed that in this area species are similar to those of the southern Iberian Peninsula. On the other hand, in the northern group, the longitudinal axis made a distinction between Ireland and UK sampling points (situated in the north central area) and Norway, where all samples presented high similarity. The island of Helgoland, the only German location represented, with its special isolated geographical situation in the southern German Bight, resembled the eastern area below Norway but nevertheless was quite unique in itself. This may indicate the partial isolation of the Helgolandic flora from the continuous European coastlines and may also be a product of its wide annual temperature gradient (Wiltshire and Manly, 2004). In general, the longitudinal gradient was not as strong as the latitudinal one. In the longitudinal case, taxa that mark such a gradient were *Codium tomentosum, Gelidium spinosum, Chylocladia verticillata, Porphyra* spp. and *Pterosiphonia* spp. towards the west. On the other hand, *Osmundea hybrida* presented a higher abundance towards the east. The main environmental variables explaining this species distribution were tidal range, salinity and wave height. The highest tidal ranges and salinities were found towards the west, while the wave height increased towards the east.

PERMANOVA results led to the conclusion that all biotypes were significantly different according to biological data (Table 3.2). Pairwise comparisons revealed that biotype A2 (Iberian Peninsula and South France) had a taxa composition different to that of biotypes B21 and B22 (pairwise comparisons t = 7.90, *P* = 0.0001 and t = 7.33, P = 0.0001 respectively). On the other hand, the weakest composition contrast was found between biotypes B1 and B22 (pairwise comparison t = 2.92, *P* = 0.0001), even though they were also significantly different.

Table 3.2. PERMANOVA results based on Bray-Curtis distances for macroalgae species data, each test was done using 9999 random permutations. Comparisons of differences between physical biotypes.

Biotypes				
Source of variation	df	MS	Pseudo-F	*P* (perm)
BIOTYPE	3	28923	37.86	0.0001**
Res	113	763.98		
Total	116			
Pairwise comparison of biotypes				
Groups	t	*P* (perm)	Unique values	
B21, A2	7.90	0.0001**	9931	
B21, B1	3.60	0.0001**	9936	
B21, B22	5.11	0.0001**	9940	
A2, B1	4.35	0.0001**	9911	
A2, B22	7.33	0.0001**	9941	
B1, B22	2.92	0.0001**	8759	

***P* ≤ 0.001

3.3.3. Biological validation within biotypes (subtypological variants)

Multivariate analyses showed the considerable biological variability inside biotypes. Regarding the meridional area (biotype A2), macroalgae data supported physical variability, since biological cluster analysis clearly distinguished three of the subtypological variants (Figure 3.4a). The main taxa responsible for the first subdivision were *Chondrus crispus, Gelidium spinosum, Bifurcaria bifurcata, Osmundea pinnatifida, Codium tomentosum, Chondracanthus acicularis* and *Cystoseira tamariscifolia*, which are more abundant in the northwestern Iberian Peninsula area. In the next subdivision, the southern coast of the Iberian Peninsula differed from the Bay of Biscay by the presence of *Colpomenia* spp., *Asparagopsis armata, Gelidium pusillum, Plocamium cartilagineum* and *Codium adhaerens*, and the lower presence of *Chondria coerulescens*.

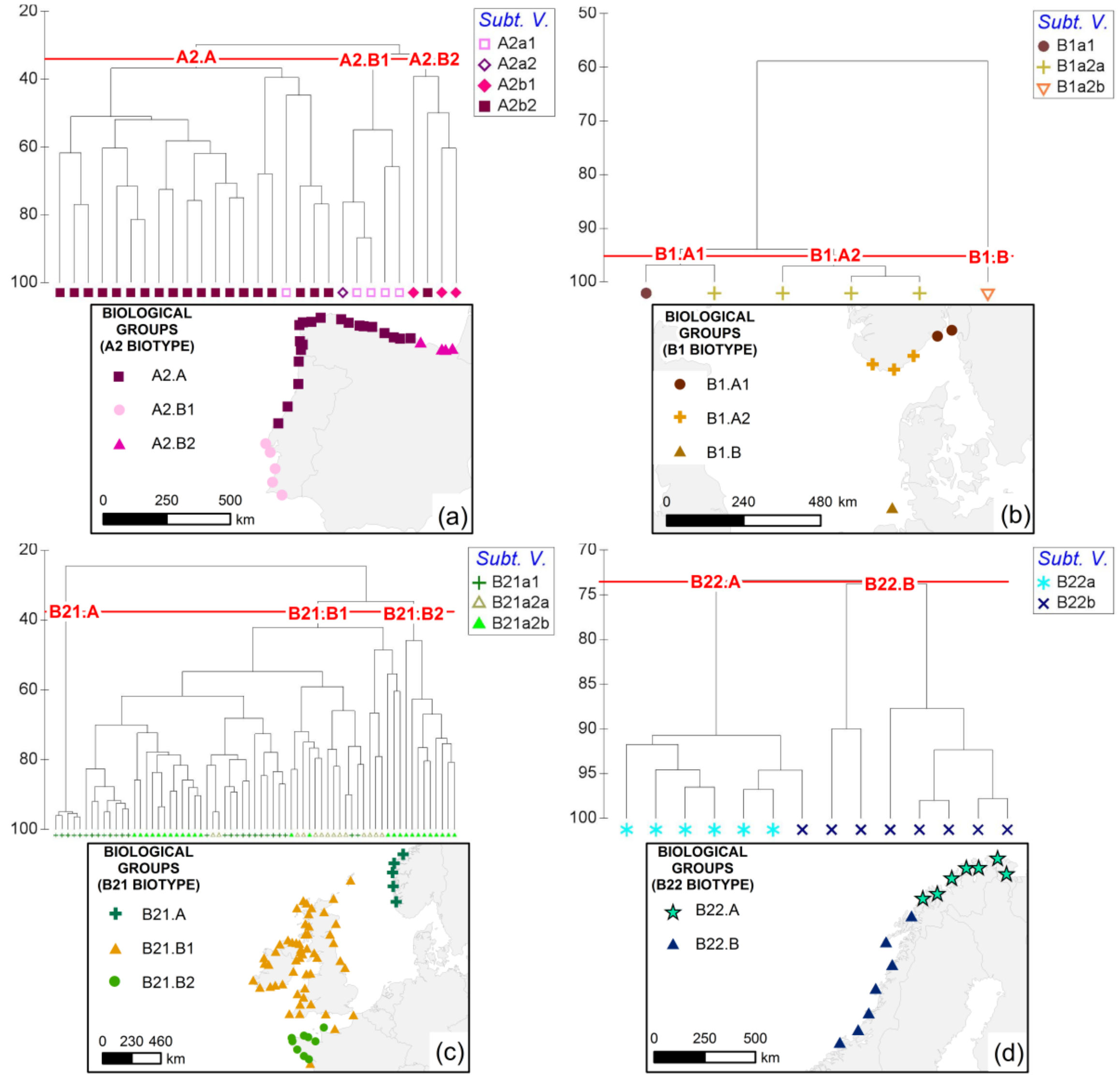


Figure 3.4. Dendrogram resulting from the classification analysis based on macroalgae species data within each biotype and their representation along the coast. From top left: (a) A2 biotype (three biological groups), (b) B1 biotype (three biological groups), (c) B21 biotype (three biological groups), and (d) B22 biotype (two biological groups). Subt. V.: subtypological variants corresponding to the physical classification.

The biological validation of subtypological variants located in the northern groups was more variable. Firstly, biotype B1 had a clear lack of data that made it difficult to derive conclusive results. However, biological groups obtained in the cluster analysis seemed similar to the physical ones, as illustrated in Figure 3.4b. Within biotype B21, biological data marked three principal groups, Norway, Brittany French coast and the UK and Ireland. Moreover, inspection of the cluster in Figure 3.4c (not represented in the map) indicated that inside this last group there were differences between northern and southern Ireland and the UK areas, associations probably related to physical variability established by Ramos et al. (2012). In regard to macroalgae taxa, *Brongniartella byssoides, Peyssonnelia* spp.*, Pterosiphonia* spp.*, Chordaria flagelliformis, Porphyra purpurea, Codium tomentosum, Porphyra* spp.*, Chylocladia verticillata, Ptilota gunneri, Colpomenia* spp.*, Gracilaria gracilis, Bonnemaisonia hamifera, Bryopsis plumosa, Desmarestia aculeata, Delesseria sanguinea* and *Petalonia fascia* were more abundant in Norway, being the main contributors to the coast differences. On the other hand, *Bifurcaria bifurcata, Chondracanthus acicularis, Catenella caespitosa* and *Gelidium spinosum* presented a higher presence around the Brittany French coast while the presence of *Ectocarpus* spp., *Osmundea hybrida* and *Leathesia* spp. distinguished UK and Ireland. Finally, the Norwegian coast was clearly grouped along a north-south gradient according to both physical and biological data. The northern samples were characterized by greater presence of *Bryopsis plumosa, Peyssonnelia* spp.*, Cladostephus spongiosus, Plocamium cartilagineum, Bonnemaisonia hamifera, Codium tomentosum* and *Halidrys siliquosa,* whereas *Urospora* spp. was more abundant in southern sites.

PERMANOVA analyses sustained above results, as detailed in Table 3.3. In all the cases it was evident that subtypological variants within each biotype were significantly different according to biological data. Differences in abundance of the different taxa were most statistically significant between subtypological variants within biotypes A2 and B21.

Table 3.3. PERMANOVA results based on Bray-Curtis distances for macroalgae species data, each test was done using 9999 random permutations. Comparisons of differences between physical subtypological variants (Subt. variant) within biotypes. *P* (MC) = *p*-values obtained using 9999 Monte Carlo samples from the asymptotic permutation distribution.

Subtyplogical variants				
A2 biotype				
Source of variation	df	MS	Pseudo-F	P (MC)
Subt. Variant	3	3237.5	3.41	0,0001**
Res	25	949.88		
Total	28			
B1 biotype				
Source of variation	df	MS	F	P (MC)
Subt. Variant	6	686.45	87.47	0,0004**
Res	3	7.85		
Total	5			
B21 biotype				
Source of variation	df	MS	F	P (MC)
Subt. Variant	2	4633.4	7.70	0,0001**
Res	64	601.52		
Total	66			
B22 biotype				
Source of variation	df	MS	F	P (MC)
Subt. Variant	1	608.51	8.02	0,001*
Res	12	75.91		
Total	13			

*P ≤ 0.01
**P ≤ 0.001

3.3.4. Biotypes biological characterisation

Biotype A2 presented the lowest number of taxa (80) (Figure 3.5). By contrast, the highest number of taxa was found in biotype B21, with 110 taxa. On the other hand, biotype A2 was characterized by the highest percentage of red algae (65%), while the northern group, biotype B22, showed the greatest percentage of brown algae (33%). According to Cheney index (1977), A2 biotype (Cheney Index of 3) showed a temperate flora, close to a mixed one (i.e., warm temperature), while the other biotypes (B1, B21 and B22; Cheney Index of 2.2, 2.5 and 2 respectively) indicated temperate-cold flora.

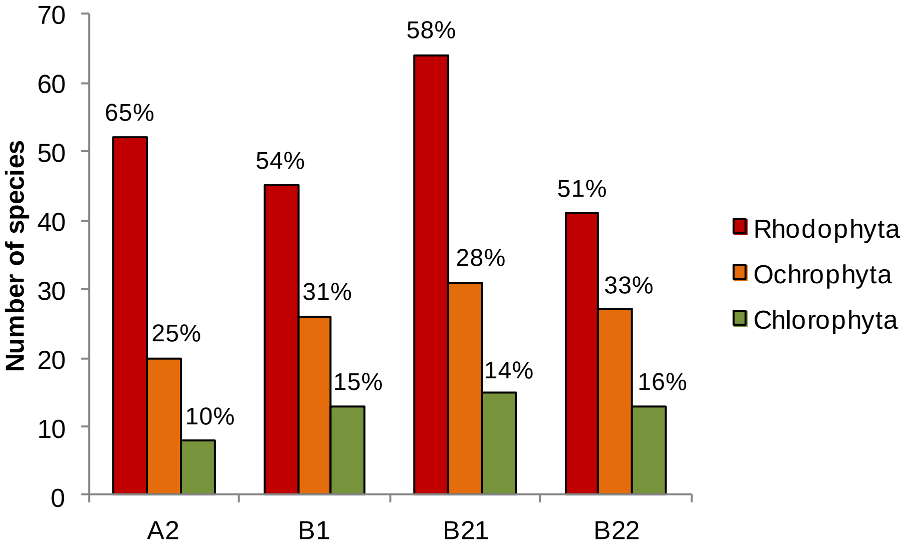


Figure 3.5. Taxa number and percentage of Rhodophyta, Ochrophyta and Chlorophyta within each physical biotype.

As can be observed from SIMPER analysis (Table 3.4), taxa that contributed to the definition of different groups were mostly macroalgae that exhibited a latitudinal distribution, according to the results obtained in the *Biotypes biological validation* section. Taxa that appeared in all the groups were *Chondrus crispus* and taxa belonging to the family Corallinaceae, both *Corallina/Ellisolandia* and crustose macroalgae (i.e., *Litophyllum, Mesophyllum,* etc.). Biotype A2 had a seaweed composition remarkably different from the other groups, where over 76% of the contribution was accounted for by 17 taxa. While in biotype B22, 27 taxa explained 53% of the accumulated similarity.

Table 3.4. List of taxa ordered by their contribution to similarity into biotypes and the cumulative contribution (Cum. Contrib.), according to results of the SIMPER analysis. Taxa whose contribution is higher than 1.75% are shown.

A2	B1	B21	B22
Corall. – crust 8.44	*A. nodosum* 1.78	*F. serratus* 4.49	*A. esculenta* 2.03
Corallina/Ellisolandia 8.43	*Ceramium* spp. 1.78	*Ulva* spp. 4.49	*A. nodosum* 2.03
Ulva spp. 7.96%	*C. crispus* 1.78	*C. crispus* 4.40	*C. flagelliformis* 2.03
C. ustulatus 6.81	*Cladophora* spp. 1.78	*Corall. – crusts* 4.35	*Corall. – crusts* 2.03
Ceramium spp. 6.28	*Corallina/Ellisolandia* 1.78	*M. stellatus* 4.24	*F. serratus* 2.03
H. scoparia 4.84	*Corall. – crusts* 1.78	*Cladophora* spp 4.06.	*F. vesiculosus* 2.03
B. bifurcata 4.32	*D. sanguinea* 1.78	*Ceramium* spp. 4.06	*L. digitata* 2.03
O. pinnatifida 4.08	*Dumontia contorta* 1.78	*Fucus vesiculosus* 3.80	*Laminaria hyperborea* 2.03
D. dichotoma 3.98	*Fucus serratus* 1.78	*Fucus spiralis* 3.77	*Palmaria palmata* 2.03
C. acicularis 3.92	*Fucus spiralis* 1.78	*Corallina/Ellisolandia* 3.65%	*Pelvetia canaliculata* 2.03
A. armata 3.04	*Fucus vesiculosus* 1.78	*Laminaria digitata* 3.39	*Phycodrys rubens* 2.03
C. crispus 2.79	*Hildenbrandia rubra* 1.78	*Palmaria palmata* 3.05	*Polysiphonia* spp. 2.03
G. spinosum 2.49	*Monostroma grevillei* 1.78	*Pelvetia canaliculata* 3.04	*Porphyra* spp. 2.03
P. cartilagineum 2.29	*P. linearis* 1.78	*Ectocarpus* spp. 3.03	*S. lomentaria* 2.03
C. coerulescens 2.07	*P. purpurea* 1.78	*A. nodosum* 2.84	*S. latissima* 1.90
Leathesia spp. 2.06	*Porphyra* spp. 1.78	*O. pinnatifida* 2.64	*D. aculeata* 1.88
Colpomenia spp. 1.75	*P. umbilicalis* 1.78	*L. articulata* 2.45	*C. filum* 1.88
	P. stipitata 1.78	*Polysiphonia* spp. 2.32	*Corallina/Ellisolandia* 1.88
	Ulothrix spp. 1.78	*D. dichotoma* 2.32	*C. purpureum* 1.88
	Ulva spp. 1.78	*Leathesia* spp. 1.87	*D. foeniculaceus* 1.88
	Urospora spp. 1.78	*O. hybrida* 1.79	*Ectocarpus* spp. 1.88
			F. spiralis 1.88
			M. alata 1.88
			O. dentata 1.88
			P. plumosa 1.88
			P. umbilicalis 1.88
			P. gunneri 1.88
Cum. Contrib.: 75.6	Cum. Contrib.: 37.3	Cum. Contrib.: 70.1	Cum. Contrib.: 52.9

3.4. Discussion

In general, results from the intertidal macroalgae community analysis were in agreement with biotypes and subtypological variants previously defined based on abiotic parameters. The biological data analyzed in this study showed the ecological relevance of the physical classification previously established along the NEA region.

Differences between macroalgal distributions from southern and northern areas reflected the same general gradient previously recognized by the physical classification (general groups A-B) despite the physical characteristic being generated from offshore location. The distribution of intertidal macroalgae along NEA region rocky shorelines show a general pattern previously known from the literature (van den Hoek, 1982a; Lüning, 1990), with a clear gradient from north to south. It becomes evident that the southern coast, i.e., Iberian Peninsula and southern France, and the rest of the study area exhibit significant differences in macroalgae species composition. These differences are based in the scarcity of several cold-temperate Ochrophyta species in the southern coast (e.g., *Ascophyllum nodosum, Fucus* spp.*, Laminaria digitata, Pelvetia canaliculata* and *Saccharina latissima*), as described by other authors based on local sampling (Fischer-Piette, 1955; Anadón and Niell, 1981) and literature review (Lüning, 1990). Most of these species require low winter temperatures (below 5-12 °C) for reproduction (Breeman, 1988), which are not achieved in the biotype A2 relatively warm waters which generally exhibit mean minimum sea surface temperatures ca. 13 °C (Ramos et al. 2012). While the above mentioned Ochrophyta generally occurred in northern coasts down to northern France, the southern area is inhabited by a majority of Rhodophyta species. In this context, the dominant presence of the brown alga *Bifurcaria bifurcata* is an exception, since it shows a warm-temperate distribution pattern colonizing rocky shores from North Africa to Ireland (Lüning, 1990).

Our data recognized a strong change in seaweed species richness and distribution in Brittany (France), which is a known boundary between colder and warmer-temperate regions (Dinter, 2001). Other authors have situated this limit further north, as van den Hoek (1975) around Ireland and Alvarez et al. (1988) around Netherlands, or further south, as the Large Marine Ecosystems (LME, Sherman, 1986). In addition, in this classification biological group B1 is subdivided into two different ecosystems: 22 (North Sea) and 24 (Celtic-Biscay Shelf). Nevertheless, it is evident that there is a major species turnover around Brittany, the definition of exact borders is generally difficult as species gradually disappear or appear along continuous coastlines and local conditions may even complicate the picture as has been outlined in diverse studies (e.g., Bartsch et al., 2012).

The suitability of the division of CW-NEA 1/26 type into two different groups (A2 and B21 biotypes) in order to carry out the IC exercise has been shown here. There is evidence for considering the northern French coast as a biogeographical transitional area, according to the results of the MDS plot and the border character discussed above. This area contains representative taxa of both A2 and B21 biotypes. In addition, the results of the cluster analysis on biological validation of biotypes (Figure 3.2) show how the B1 biological group is subdivided into the French coast and the rest of the area (UK and Ireland) according to macroalgae distribution.

On the other hand, A1 biotype suitability has not been tested due to the lack of biological data. Nevertheless, it is widely recognized that the Canary Islands and Madeira are a part of a unique floristic marine biogeographical province (e.g., van den Hoek, 1975; Alvarez et al., 1988) and have also been differentiated from other regions in general coastal classification systems (Sherman, 1986). These archipelagos have a rich marine flora with co-occurrence of floristic elements from the Mediterranean Sea, the tropical Western Atlantic Ocean and the warm-temperate North Atlantic coasts (Haroun et al., 2002).

Water temperature is the principal environmental factor causing the marked latitudinal gradient governing the geographical distribution of species on a large area (Lüning, 1990). Species present all along the study area (i.e., *Ulva* spp. and *Chondrus crispus*) are those that exhibited a broad temperature range for growth, as between 0 and 28 °C in the case of *Chondrus crispus* (Fortes and Lüning, 1980). Furthermore, van den Hoek (1975) suggested that, within their natural temperature limits, macroalgae are capable of completing their entire life cycle, surviving adverse conditions and competitors.

Macroalgae distribution showed differences at a higher scale that may be related to the subtypological variants. The differentiation inside biotype A2 of the north-western Iberian Peninsula in relation to the rest of the southern area is remarkable. This coast is characterized by constant upwelling (Alvarez et al., 2008) and thereby by colder surface waters in August, between 17 and 19 °C (Casares, 1987). Due to this circumstance some arctic to cold-temperate species such as *Desmarestia aculeata, Chorda filum, Saccharina latissima, Dumontia contorta, Palmaria palmata, Ascophyllum nodosum, Fucus serratus, Laminaria hyperborea, Pelvetia canaliculata, Himanthalia elongata* and *Halidrys siliquosa* are still present here (Lüning, 1990). On the other hand, locations along the Bay of Biscay are situated on the bottom of the MDS graph indicating more affinities to the southern European flora. This coast is inhabited by many warm-temperate species that are otherwise present in Morocco and South Portugal, due to regular superheating of the water in summer because of coast geographical structure and the absence of permanent strong currents.

Along the continental coast around the North Sea (B1 biotype) the lack of data was inevitable due to the soft-bottom nature of the shore. Natural rocky intertidal shores with seaweeds are generally absent except at the island of Helgoland (Bartsch and Kuhlenkamp, 2000) which is situated in the southern German bight 60 km offshore. For the Skagerrak and Kattegat region of the North Sea further work has been done by Pedersen (Pedersen, 2012) analyzing particular chemical and physical properties (geography and bathymetry, circulation and water masses, salinity, etc.). Their results are consistent with the biotype concept of Ramos et al. (2012), dividing the coasts of Skagerrak and Kattegat into two different groups.

Despite the general agreement with the main objective of this work, a methodological question arises for debate. The most likely reservation refers to the macroalgae data provided by each MS. In fact, this is the pitfall of all phytogeographic studies, which are all necessarily based on floristic comparisons (van den Hoek, 1975). In this study the compilation of biological information has been carried out in a homogeneous way, while the underlying data were obtained by different sampling methodologies and with different objectives. In Norway, for example, the macroalgae dataset is based on a tabulated catalogue of all benthic macro-organisms along the Norwegian coastline. This very complete database contains information about macroalgae species along each stretch of Norway. Information provided by other MS was different and mostly not as exhaustive. It could be the reason why if we analyzed the cluster analysis in Figure 3.2 without taking into account Norwegian samples, biological groups and physical biotypes coincide with more accuracy. Although data from exposed coasts have been selected, another reason for the mismatch between macroalgae organization and biotypes can be the intrinsic characteristics of the Norwegian shore, with fjords all along the coast. It is known that there is a "fjord effect" that decreases wave action and salinity from the mouth to the inner fjord and reduces the number of species (Klavestad, 1978). Furthermore, values of physical variables in the fjords intertidal areas could be a bit different of the ones obtained 5 km away from the coast. Therefore, this methodology may be not adequate in Norwegian coast, while it works in the rest of the European area.

The classification approach shown in this paper proposes a simple and appropriate tool for management and conservation efforts. Specifically, the WFD implementation process requires the establishment of typologies for comparisons between different assessment systems. The homogenous data base obtained can allow us for the interpretation and identification of potential habitats of macroalgae species and communities and for the establishment of general reference conditions for different and wider coastal areas. Smaller WFD water types such as the unique N5 water body around the island of Helgoland (Germany) may profit from this situation as it may become associated to a bigger biotype and then comparisons with other reference conditions become easier. Additionally, the information provided here and in Ramos et al. (2012) may be useful to accomplish work related to climate change issues. The detection of climatic variables that determine range boundaries of species or the identification and prediction of shifts in species distribution under future warming scenarios have been studied (e.g., Mieszkowska et al., 2006). Now these may be judged and modelled over wider areas along NEA shores, with a profound quantitative baseline of the distribution of abiotic factors and concurrent seaweed diversity.

In conclusion, this paper confirms the biological relevance of the coastal classification established by Ramos et al. (2012). The distribution of intertidal macroalgae shows both latitudinal and longitudinal gradients related with physical factors. The latitudinal gradient is most important and is associated with the sea surface temperature gradient. Though it is difficult to establish clear distributional borders in a natural environment, it seems clear that there is a transition biogeographical area around Brittany (France), which separates the southern from the northern area of the NEA coast (van den Hoek, 1975; Dinter, 2001). In addition, within the northern area there is another marked boundary, which differentiates between northern France, UK and Ireland and the rest of the coast. Therefore, the classification approach proposed offers an objective statistical tool for the definition of ecologically relevant regions, which can be beneficial for environmental protection and management of marine zones.

Chapter IV

Coastal classification at regional scale

Chapter IV. Coastal classification at regional scale

This chapter is an edited version of the research article in press in the journal Marine Ecology, by Ramos, E., Puente, A., Juanes, J.A., with the title "An ecological classification of rocky shores at a regional scale: a predictive tool for management of conservation values".

Abstract

The ecological classification of coastal waters has become an important issue in ecosystem water quality assessment. Previous studies have suggested that abiotic variables seem to be a suitable alternative to biological data for classifying coastal areas at different scales. This work proposes a downscaling methodology for the classification of coastal waters at a regional scale within the NE Atlantic based on standardised data and objective decision rules. Physical variables (temperature, wave exposure, tidal range and radiation) were selected because of their ecological role, availability and statistical decision rules. This information was based on satellite data and mathematical modelling of natural coastal processes. The N and NW Spanish coastline was subdivided into forty-one 20 km segments that were classified according to physical variables using the Self-Organizing Map (SOM) and k-means algorithms. To validate the classification with biological data, 21 sites representing the entire range of physical typologies in the study area were simultaneously and consistently sampled. Intertidal macroalgae were identified in each of ten quadrats of 50x50 cm for 2-3 transects per site, according to a stratified sampling procedure. The coverage of macroalgae was obtained by photographic analysis. The physical classification shows four typologies: Lower Rias, Upper Rias, West Cantabric and East Cantabric. Statistical analyses confirmed the ecological significance of these typologies at the tidal levels where seaweeds are the major structural element (lower and middle intertidal). According to the biological data, the greatest differences were found between the Upper Rias and the rest of the N and NW Iberian Peninsula coast. Thus, the classification methodology has potential application as a management tool.

4.1. Introduction

Despite their significant value for the conservation and maintenance of biodiversity and provisioning of ecosystem services, coastal environments have been greatly impacted by human activities (Costanza et al., 1997). Therefore, the management of coastal zones in the form of action plans is urgently need to reach preservation goals (Boesch, 2006). One of the first steps is establishing ecologically homogenous types by their abiotic and biotic characteristics. Thus, ecologically sound marine classifications emerge as a useful predictive tool for a variety of ecological quality assessment and conservation purposes.

The development of a classification system must first take into account the spatial domain and the working scale required for each specific research objective. Then, additional important aspects such as those associated with the spatial resolution (e.g., grid size), the type of indicator (e.g., significant wave height vs. shear stress), and the source of physical (e.g., satellite vs. modelling) or biological data (e.g., qualitative vs. quantitative abundances) should be established. In this way, it would be possible to develop a hierarchical procedure suitable for analysing the variability in the environmental conditions in different coastal areas and scales. Following the classification approach established along the NE Atlantic coast (Ramos et al., 2012; Ramos et al., 2014), clear patterns of variability were observed in analysing both the entire area and the coastal shores within a certain typology (e.g., biotype A2). Further downscaling analyses may be carried out to consider the distribution of biotic and abiotic variables on a regional scale. These analyses might look for variability at certain ecotones, such as those at well-known distribution limits for representative species according to previous scales.

Regarding the distribution of macroalgae, the entire Bay of Biscay is a transitional area located between the southern warm region (Cantabric sea) and the northern cold region (French Brittany) (van den Hoek, 1982a; Lüning, 1990). Despite all the studies carried out along this area (e.g., Miranda, 1943; Fischer-Piette, 1963; Fernández and Niell, 1982; Anadón and Fernández, 1986), there has never been a comprehensive and homogeneous inventory (taxonomy, season, relation with physical variables, etc.) that provides adequate knowledge of the current distribution of macroalgae species for marine spatial management. This type of information would be a key element for the validation of any kind of regional classification developed in this coastal area.

The aim of this study was the development and validation of a downscaling methodology for the more detailed classification of intertidal rocky shores at a regional scale, based on standardised data and objective decision rules following the procedure established along the NE Atlantic coast by Ramos et al. (2012; 2014). This goal is addressed through the objectives of i) developing a coastal classification based on physical variables associated to the distribution of intertidal assemblages in the southern Bay of Biscay and ii) verifying the suitability of the previous classification with standardised biological data (the actual distribution of intertidal macroalgae species).

4.2. Methodology

4.2.1. Study area

The study was carried out on the N and NW shores of the Iberian Peninsula (Southern Bay of Biscay), between the borders of Portugal (41°52'N, 8°52'W) and France (43°24'N, 1°48'W) (Figure 4.1). This coastline of ca. 2350 km within the A2 biotype of the NE Atlantic classification (Ramos et al., 2012) encloses two Atlantic faces. The Northern face is located within the southern part of the Bay of Biscay and corresponds to the Cantabric Sea. The Western face is extended along the Atlantic Ocean and is characterised by the presence of rias, inner areas protected from the influence of oceans on both their own configuration and the islands present in the river mouths.

Regarding general oceanographic and meteorological processes, the area is associated with a climate Cfb (oceanic climate, warm and wet) according to the Köppen classification, which is characterised by average temperatures exceeding 10 °C at least four months a year and by a weak summer. The coast is normally exposed to large fetches, generating waves with heights between 2.5 and 3 m. The tide corresponds to a semi-diurnal regime, with two high tides and two low tides ranging between 3 and 4 m.

To apply a uniform procedure for the division of the entire study area, coastal sections of equal length were established according to the methodology of Ramos et al. (2012), which was adapted for this scale. For this purpose, a line parallel to the shoreline was drawn at a depth of 150 m by means of the program ArcGis, beginning at the boundary of the border with Portugal, in Galicia, and ending at the French border in the Basque Country. This depth allows satellite sensors to provide reliable data and the physical data found here can be associated with the environmental conditions along the intertidal. Then, the line was cut into segments of 20 km (considered an optimal distance for a regional scale study), and the boundaries of these sections were projected to the shore. Thus, 41 segments were obtained on a line at 1:250000 scale. Finally, a serial number (1-41) was assigned to each segment, beginning from the west (Figure 4.1).

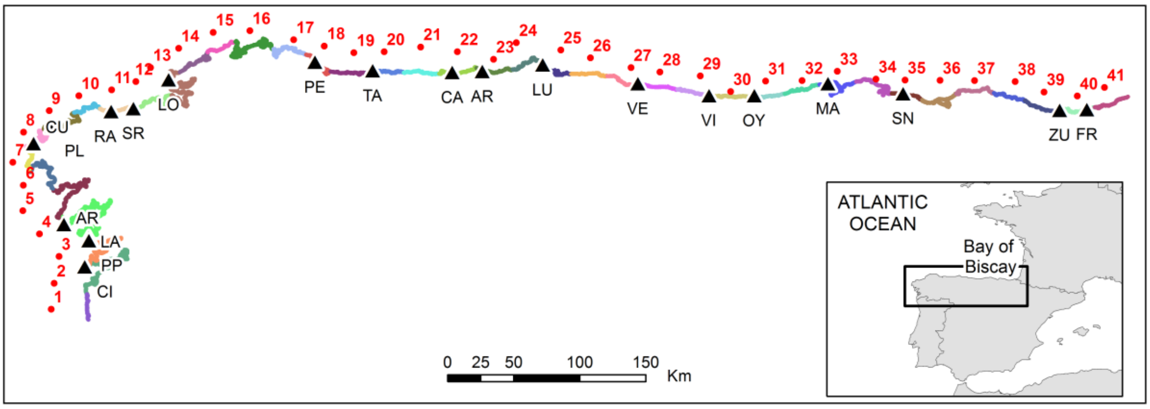


Figure 4.1. Location of the study area. Preliminary division of the N and NW Iberian Peninsula coastline into segments. Location of biological data sampled sites represented by triangles: CI (Cíes); PP (Praia Pociñas); LA (La Lanzada); AR (Area Basta); PL (Praia Lobeiras); CU (Coido de Cuño); RA (Razo); SR (Sorrizo); LO (Lobadiz); PE (San Pedro); TA (Tapia Casariego); CA (Campiechos); AR (Area Basta); LU (Luanco); VE (La Vega); VI (Vidiago); OY (Oyambre); MA (La Maruca); SN (Sonabia); ZU (Zumaia); and FR (Los Frailes).

4.2.2. Physical classification

4.2.2.1. Collection of physical data

The first step was the selection of abiotic variables that best met the following criteria based on Ramos et al. (2012): (1) significant spatial variability at the regional level in the study area, (2) proposed in other classifications at similar scale (IMCRA, 1998; WFD, 2000/60/EC; Connor et al., 2004; Lombard et al., 2004; Schernewski and Wielgat, 2004;

Mount et al., 2007; Snelder et al., 2007), (3) related to the geographical distribution of macroalgae communities (Lewis, 1955; Levin and Paine, 1974; van den Hoek, 1982a; Lüning, 1990; Wallentinus, 1991; Hanelt et al., 1993; Rinne et al., 2011; Spatharis et al., 2011), (4) possibility of obtaining quantitative and standardised data at regional scale within the study area and (5) not mutual influence (intercorrelation coefficient lower than 0.95) between indicators of the variables. The physical variables selected were sea surface temperature (maximum and minimum values), photosynthetically active radiation (annual mean and minimum values), wave height (annual mean) and tidal range (annual mean).

All variables were calculated in "indefinite depths" at the central point of each segment, as previously defined (Figure 4.1). The uniform depth of the measurement points allowed the data obtained by remote sensing to be homogeneous and comparable. The specific procedures for obtaining data were adapted from Ramos et al. (2012) (Table 4.1). The exposure to wave action was represented by significant wave height (Hs), based on a global wave dataset simulated with the model WaveWatch III and driven by NCEP/NCAR reanalysis of winds and ice fields (GOW, Reguero et al., 2012).

Table 4.1. Data sources and methodologies for the quantification of each environmental variable (see text for the full names of acronyms). Slightly modified from Ramos et al. (2012).

Variables	Source	Data series		
		Period	Temporal resolution	Spatial resolution
SST	AVHRR Pathfinder v.5.0. project	1981-2008	Monthly average	4 km
PAR	SeaWIFS sensor	1997-2009	Monthly average	9.28 km
Tidal range	TOPEX/Poseidon mission	2007-2008	Minute	7 km
Wave height	Reanalysis GOW (model WaveWatch III)	1992-2009	Monthly average	0.1°

According to the spatial resolution of each data series (Table 4.1), tidal range, sea surface temperature (SST) and photosynthetically active radiation (PAR) were obtained from the point nearest the reference point with satellite information (central point of each segment in the 150 m depth line, cf. Figure 4.1). By contrast, wave height was acquired from the closest point to the reference points for which numerical analysis information was available, always towards deep water. This method avoided any problems related to the modification of wave regimes because of bathymetry and the dissipation characteristics of shallow waters.

4.2.2.2. Classification procedure

The coastal segments were then grouped according to physical data series, combining two techniques: (1) Self-Organizing Maps (SOM) (Kohonen, 2001), a technique included in artificial neural networks (ANNs), and (2) the K-means algorithm (Hastie et al., 2001). The SOM is a classification method that detects patterns or classes in a set of data, preserving the neighbouring relations. This means that similar clusters in the multidimensional space are located together on a 2D grid that allows the data to be intuitively visualised. The starting point of this technique is a data sample in which N is the total number of data points to be classified. The ANN is “trained” using an iterative learning algorithm. The process includes a self-organizing neighbourhood mechanism, so neighbouring clusters of the winning reference vector in the 2D lattice space are also adapted toward the sample vector, thus projecting the topological neighbourhood relationships of the high-dimensional data space onto the lattice.

Map size determination is one of the key points in SOM application. In this study, the optimum map size (number of units) was chosen based on the heuristic formula proposed by Vesanto et al. (2000), $M = 5\sqrt{N}$ where M is the number of map units and N is the number of samples of the training data. The number of units chosen was also supported as an optimum solution based on the minimum values for quantisation and topographic errors by training with different map sizes. The quantisation error (QE) is the average distance between each data vector and its best matching unit (BMU). This error measures map resolution (Kohonen, 2001). Topographic error (TE) measures map quality, and it represents the proportion of all data vectors for which 1st and 2nd BMUs are not adjacent (Kiviluoto, 1996). Before the SOM training, each variable was normalised at an interval of [0, 1] by a linear transformation in each segment.

The number of groups obtained with the application of the SOM was high for the creation of a simple, manageable classification. Thus, as the second step of the physical classification, a k-means algorithm was applied to cluster the trained map. The classification procedure starts with a random initialisation of the centroids. On each interaction, the data nearest to each centroid is identified and the centroid is then redefined as the mean of the corresponding data. The algorithm is iteratively moved until the intragroup distance is minimal and the process converges. The number of k-means groups was justified according to the minimum Davies Bouldin Index (DBI) for a solution with low variance within clusters and high variance between clusters (Negnevitsky, 2002).

SOM analyses were conducted using Matlab 7.7 and the SOM coding solution based on SOM Toolbox for Matlab 5 (Vesanto et al., 2000).

4.2.3. Biological validation and characterisation

4.2.3.1. Collection of macroalgae data

To validate the physical classification, a homogenous and standardised sampling methodology was carried out in 21 sites along the N and NW Iberian Peninsula, distributed as represented in Figure 4.1. Field surveys were carried out during the low spring tides in April 2010. The site selection took into account that the sites follow an equidistant distribution throughout the study area (1-5 segments of 20 km between consecutive surveyed sites) and that they were mostly “exposed” to wave action, representative of the area, comparable and accessible. At each site, three transects perpendicular to the coast were selected, separated by 50-100 m and characterised as block and platform zones, with obvious coverage of macroalgae (approximately 90%) and with a characteristic pattern zonation (Figure 4.2). Detailed information about transects is summarized in Table 4.2.

Figure 4.2. Example of transects perpendicular to the coast (La Lanzada, Campiechos and Luanco sites).

Table 4.2. Georeference, direction, length and altitude of transects.

Site	Transect	Latitude (N)	Longitude (W)	Direction	Length	Altitude
Cíes	1	42°14'6.64''	8°53'59.45''	45°	44	5.1
	2	42°14'3.41''	8°53'59.72''	45°	35	-
Praia das Pociñas	1	42°24'48.94''	8°52'18.65''	150°	77	2.6
	2	42°24'49.47''	8°52'20.65''	170°	19	1.5
La Lanzada	1	42°25'57.06''	8°52'28.54''	225°	26	3.0
	2	42°25'58.41''	8°52'31.49''	173°	22	2.8
Area Basta	1	42°31'23.80''	9°2'30.00''	335°	27	4.1
	2	42°31'24.62''	9°2'28.49''	300°	18	4,3
	3	42°31'29.17''	9°2'29.35''	310°	14.5	1.8
Coido de Cuño	1	43°4'27.27''	9°14'58.47''	260°	46	4.5
	2	43°4'27.27''	9°14'58.47''	260°	50	1.7
Playa Lobeiras	1	43°11'41.10''	9°7'10.46''	290°	24	2.3
	2	43°11'43.26''	9°7'10.14''	285°	21.8	1.4
	3	43°11'43.00''	9°7'9.25''	0°	25	1.7
Razo	1	43°17'32.99''	8°43'16.08''	320°	13.4	5.9
	2	43°17'32.56''	8°43'15.21''	40°	-	3.4
Sorrizo	1	43°18'50.07''	8°34'8.71''	60°	31	6.5
	2	43°18'49.01''	8°34'7.81''	60°	34	5.4
	3	43°18'47.46''	8°34'6.87''	70°	26.8	-
Lobadiz	1	43°30'37.45''	8°19'40.78''	280°	38.7	6.1
	2	43°30'36.26''	8°19'40.48''	290°	23.6	5.5
	3	43°30'33.77''	8°19'43.11''	30°	22.3	4.4
San Pedro	1	43°37'47.31''	7°19'56.92''	90°	21	4.7
	2	43°37'46.19''	7°19'57.62''	70°	40.5	5.8
	3	43°37'43.74''	7°19'58.34''	90°	41	6.6
Tapia Casariego	1	43°34'16.77''	6°56'20.46''	340°	22	5.8
	2	43°34'15.72''	6°56'20.18''	60°	31	5.1
	3	43°34'14.09''	6°56'19.78''	30°	30.5	5.0
Campiechos	1	43°33'35.25''	6°23'46.63''	50°	51	6.1
	2	43°33'31.00''	6°23'30.73''	50°	71	5.4

Table 4.2. Continued.

Site	Transect	Latitude	Longitude	Direction	Length	Altitude
Concha de Artedo	1	43°33'59.66''	6°11'29.40''	71°	37	5.1
	2	43°33'58.70''	6°11'29.08''	72°	38.7	4.1
	3	43°33'57.90''	6°11'28.89''	69°	60	4.2
Luanco	1	43°36'42.04''	5°46'50.86''	63°	52	5.0
	2	43°36'41,04''	5°46'50.50''	103°	36	7.5
	3	43°36'42.94''	5°46'51.19''	39°	35	7.1
La Vega	1	43°28'58.08''	5°7'53.34''	311°	66	5.3
	2	43°29'0.11''	5°7'47.28''	10°	31	4.3
	3	43°28'57.18'	5°7'58.83''	320°	94	2.4
Vidiago	1	43°24'8.24''	4°38'50.92''	301°	65	4.8
	2	43°24'7.23''	4°38'53.29''	292°	148	7.0
Oyambre	1	43°24'6.40''	4°20'18.95''	69°	125	7.8
	2	43°24'7.64''	4°20'18.74''	62°	53	2.9
La Maruca	1	43°28'57.00''	3°50'10.00''	346°	61.9	8.7
	2	43°28'56.00''	3°50'13.00''	8°	71	9.3
Sonabia	1	43°24'56.00''	3°19'31.00''	32°	38	5.3
	2	43°24'56.00''	3°19'32.80''	290°	24	5.4
Zumaia	1	43°18'80.00''	2°15'33.00''	287°	88	7.1
Los Frailes	1	43°18'26.00''	2°4'27.36''	350°	36	6.9
	2	43°18'27.00''	2°4'30.00''	32°	18.5	5.6

A stratified sampling was carried out, dividing each transect into four areas and taking into account the characteristic zonation pattern of the study area: 1) Lower intertidal (belt of brown algae); 2) Middle intertidal (belt of red algae); 3) Upper intertidal (barnacles and limpets dominance, with scattered algae); and 4) Supralittoral (presence of lichens and periwinkles). As can been observed in Figure 4.3a, the sample stations were distributed at equal distances, three in the lower and middle intertidal and two in the upper intertidal and supralittoral. The sampling unit was standardised using a 50 x 50 cm grid.

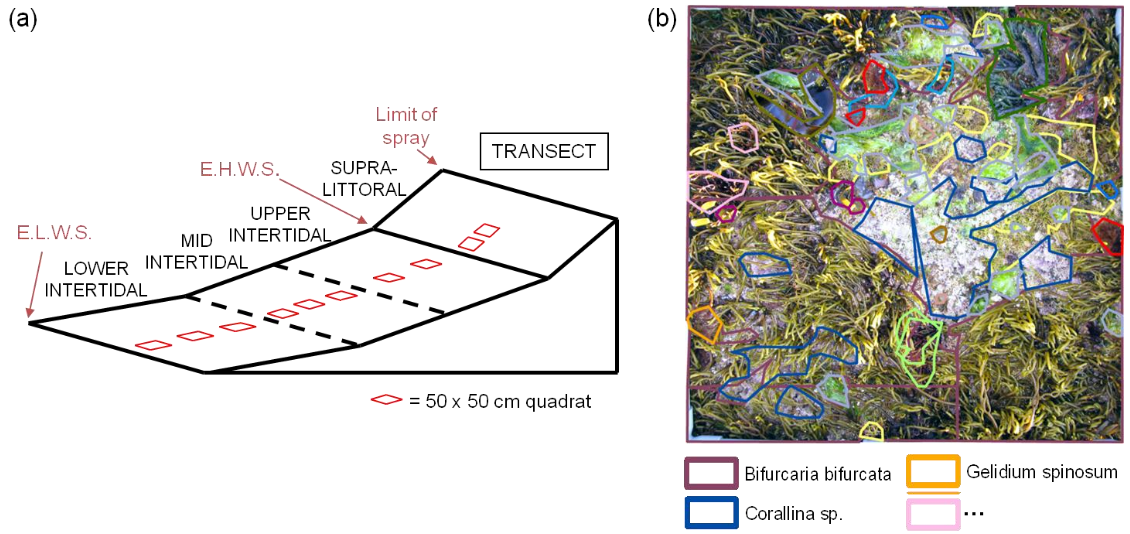


Figure 4.3. (a) Distribution of sampling stations (quadrats) along each transect. (b) Polygons identified and outlined in photographs using ArcGis for the quantification of macroalgae taxa cover in each quadrat.

Algae were identified to the species level in situ or assigned to higher taxonomic categories when species identification was not possible. In that case, the taxa cover was obtained by photographic analysis. For this purpose, at least one photo of the grid was taken at each station. A digital camera was placed in a structure that allowed the field crew to take all the photos at the same height and parallel to the rocky surface (Figure 4.4). Then, the photographs were georeferenced and adjusted to real size in ArcGIS. Macroalgae taxa were identified and outlined to create polygons whose areas were measured and registered (Figure 4.3b).

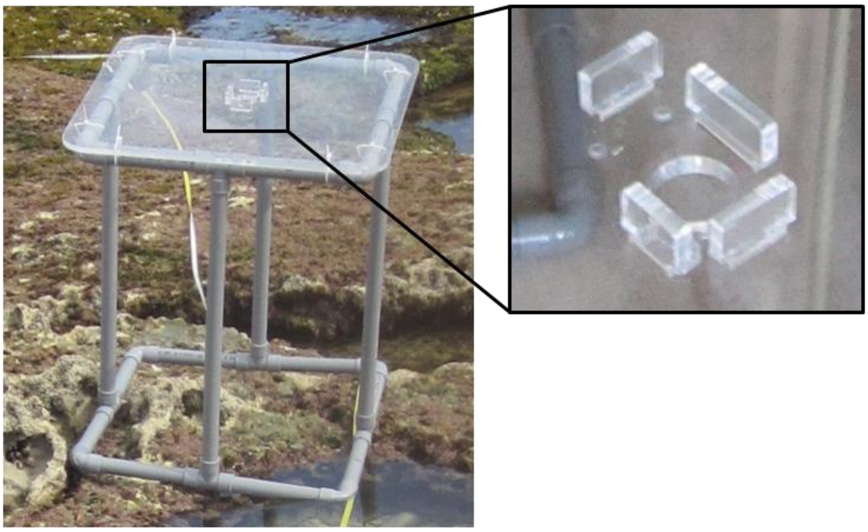


Figure 4.4. Structure where the camera was placed.

4.2.3.2. Biological validation and characterisation procedure

To test the adjustment between the macroalgae distribution and physical typologies, several statistical analyses were carried out. Four matrices with cover values averaged by transect were created, one for each tidal level. Firstly, the specific richness and Shannon-Wiener diversity were calculated. Then, a MDS analysis was carried out with square root transformed data and Bray-Curtis similarity coefficients to identify patterns and gradients in the macroalgae communities. A permutational multivariate analysis of variance (PERMANOVA, Anderson, 2001) was performed to detect significant differences in the taxa composition among different typologies. A two-way crossed design was applied considering two fixed factors: typology and tidal range. Significant terms and interactions were investigated using a posteriori pairwise comparison with the PERMANOVA-t statistics. Taxa making the greatest contribution to the similarity inside typologies were detected using SIMPER analysis only within the tidal ranges where the differences were significant.

Finally, the taxa that contributed most to the dissimilarity between typologies according to SIMPER analysis were visualised on the SOM, which had been previously trained with physical data. In this way, the patterns in macroalgae communities could be identified in relation to environmental data and physical typologies because the gradient distribution was visualised in the same figure.

All statistical analyses were carried out using the PRIMER-E (v.6 + PERMANOVA) package (Clarke and Gorley, 2006), except the representation of taxa on the SOM map, which was carried out using Matlab 7.7.

4.3. Results

4.3.1. Physical classification

The averaged values of the physical variables along the study area are represented in Figure 4.5. The maximum temperature increased eastward, reaching its peak at the coast of the Basque Country. However, the minimum temperatures were very similar at both Cantabrian border areas and, slightly lower to the east. This phenomenon is related to the strong seasonality of SST. From November to April, temperatures do not vary greatly throughout the study area, while in summer, the differences are approximately 5°C (August), with much higher values towards the east. Regarding radiation, PAR had its maximum in the western region, with a sharp decline from Ortigueira (A Coruña). By contrast, the minimum radiation did not follow a clear trend. Wave height increased towards the west. Finally, the tidal range followed a trend opposed to that of wave height. It was highest around the inner part of the Bay of Biscay, with a 0.7 m difference between the eastern and western coast.

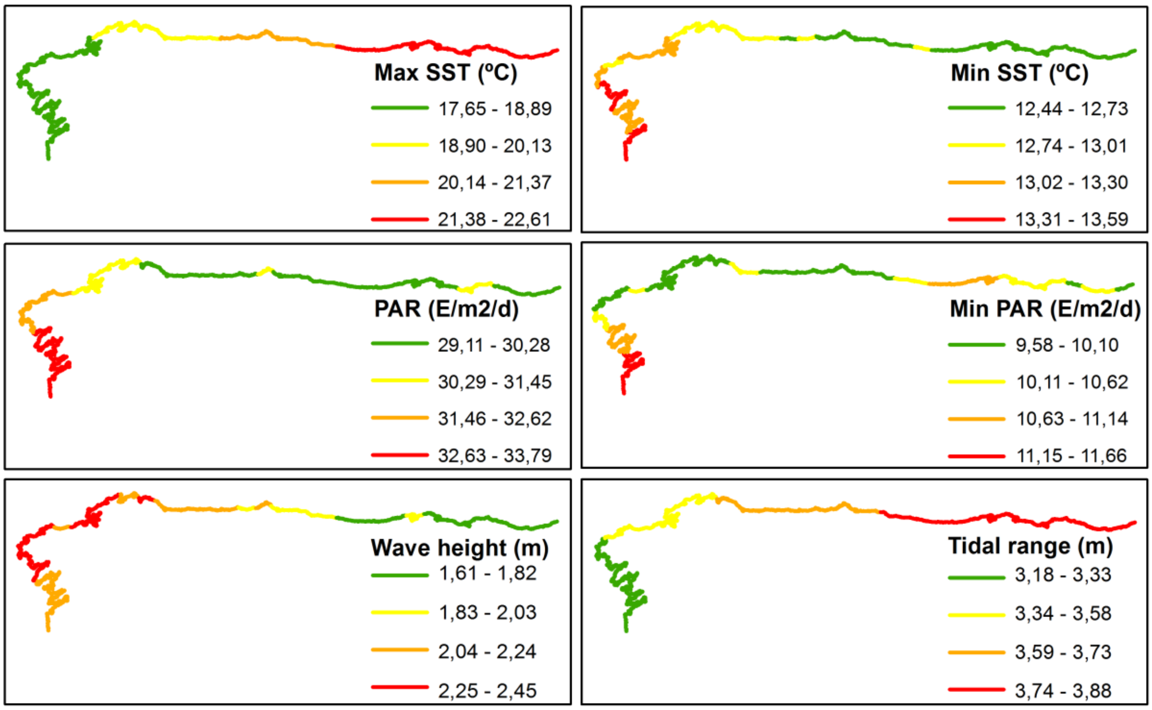


Figure 4.5. The spatial distribution of the variables used in the physical classification along the N and NW Iberian Peninsula region. Visualisation of data using four levels at equal intervals. From top left: maximum SST, minimum SST, average PAR, minimum PAR, average wave height and average tidal range.

The dataset of the six physical indicators characterising each segment was used to train the SOM and was subsequently projected onto a two-dimensional (2D) map. Based on the heuristic formula explained above and the minimum quantisation and topographic errors, the map size selected was 32 units (8 x 4 neurons). This way, the map trained had a quantisation error of 0.15 and a null topographic error. This map thus closely preserved the typology of the input data (Kohonen, 2001) and was relevant for subsequent interpretations.

As seen in the results shown in Figure 4.6a, the SOM technique simplified clustering of the data set so that it was possible to observe intuitively how the segments are grouped according to their characteristics. However, for a more manageable and simplified classification, the K-means technique was applied to the groups obtained from the SOM. Davies Bouldin index (DBI) was calculated for 2 to 9 k-means clusters, obtaining values between 0.54 and 0.68.

Considering the minimum DBI (0.54), it was found that 4 was the optimal number of groups. Figure 4.6a shows the limits of the groups obtained with the K-means technique. Clusters were also presented on a geographical map of the study area to facilitate interpretation (Figure 4.6b).

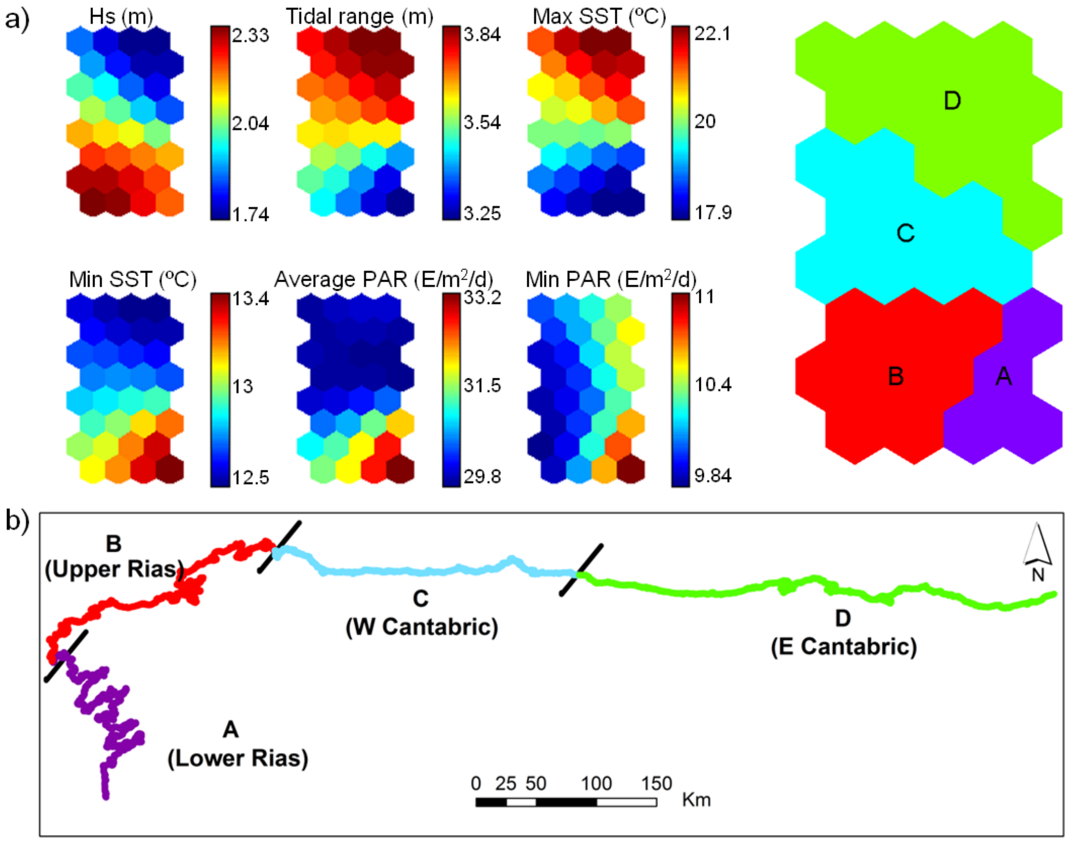


Figure 4.6. (a) Left, Gradient analysis of each physical variable on the trained SOM. Right, K-means results on the SOM plane. (b) Map of the typologies obtained in physical classification (based on SOM and k-means statistical analyses results).

Thus, the coast was classified into four typologies (mean and standard deviation values for each typology are summarised in Table 4.3):

- Lower Rias (A): this type encompassed the area from the border with Portugal to Finisterre Cape. It was characterised by a lower tidal range, the maximum SST and a higher minimum temperature and radiation.

- Upper Rias (B): this type was established from Finisterre Cape to Ria de Vivero (in Lugo). It presented the maximum values of wave height.

- West Cantabric (C): this type included the area from Ria de Vivero to Ria Villaviciosa in Asturias (near Peñas Cape). This was a transitional group with physical data between the western and the eastern part of the study area.

- East Cantabric (D): this type comprised the eastern part of Asturias (from Ria Villaviciosa), Cantabria and Basque Country provinces. This area was characterised by a lower wave height, minimum SST and average solar radiation, and a higher tidal range and maximum SST.

Table 4.3. Average and standard deviation values for each physical variable in each typology.

Typology	Max SST (°C)	Min SST (°C)	PAR (E/m^2/day)	Min PAR (E/m^2/day)	Hs (m)	Tidal range (m)
Lower Rias	17.8 ± 0.13	13.4 ± 0.12	33.2 ± 0.49	11.0 ± 0.51	2.2 ± 0.08	3.2 ± 0.03
Upper Rias	18.5 ± 0.70	13.0 ± 0.12	31.3 ± 0.50	9.9 ± 0.22	2.3 ± 0.07	3.5 ± 0.10
W Cantabric	20.3 ± 0.31	12.8 ± 0.09	29.8 ± 0.28	9.9 ± 0.19	2.1 ± 0.11	3.7 ± 0.04
E Cantabric	21.9 ± 0.49	12.6 ± 0.11	29.9 ± 0.40	10.4 ± 0.27	1.8 ± 0.08	3.8 ± 0.03

4.3.2. Biological validation and characterisation

A total of 400 quadrats were examined, distributed along the 21 sites, and 70 different macroalgae taxa were identified (taxa list in Table 4.4). Among these, the most abundant taxa were *Corallina officinalis/Ellisolandia elongata, Gelidium spinosum, Litophyllum incrustans* and *Ulva* spp., with wide distributions along the study area. Box plots (Figure 4.7) showed that the species richness and Shannon-Wiener diversity indices were around the same range in the lower and middle intertidal (averages between 15 and 20 in the case of richness and between 1.5 and 3 for diversity). As expected, these values were lower in the upper intertidal zone. In general, both indices decreased from west to east. The greatest differences were found in diversity between the Lower Rias (typology A) and the East Cantabric (typology D) in the lower intertidal and between the Lower Rias again and the West Cantabric (typology C) in the middle intertidal. The supralittoral zone was not represented because the values obtained were not illustrative, since in this zone macroalgae species are scarce and its distribution did not show any specific pattern.

Table 4.4. Taxa list of intertidal rocky shore macroalgae identified along the study area.

Chlorophyta

Bryopsis plumosa
Codium adhaerens
Codium tomentosum
Ulva spp.

Ochrophyta

Bifurcaria bifurcata
Cladostephus spongiosus
Colpomenia peregrina
Cutleria multifida
Cystoseira baccata
Cystoseira tamariscifolia
Desmarestia aculeata
Dictyopteris polypodioides
Dictyota dichotoma
Ectocarpales
Fucus serratus
Fucus vesiculosus
Himanthalia elongata
Laminaria spp.
Leathesia marina
Padina pavonica
Ralfsia verrucosa
Saccorhiza polyschides
Sargassum muticum
Scytosiphon lomentaria
Stypocaulon scoparium
Undaria pinnatifida

Rhodophyta

Ahnfeltia plicata
Apoglossum ruscifolium
Asparagopsis armata
Boergeseniella thuyoides
Bonnemaisonia hamifera
Calliblepharis ciliata
Caulacanthus ustulatus
Ceramium spp.
Champia parvula
Chondracanthus acicularis
Chondracanthus teedei
Chondria coerulescens
Chondrus crispus
Chylocladia verticillata
Corallina officinalis/Ellisolandia elongata
Cryptopleura ramosa
Falkenbergia rufolanosa
Gastroclonium ovatum
Gelidium corneum
Gelidium pusillum
Gelidium spinosum
Gigartina pistillata
Gymnogongrus crenulatus
Halopithys incurva
Halurus equisetifolius
Hildenbrandia rubra
Hypoglossum hypoglossoides
Jania rubens
Laurencia obtusa
Lithophyllum incrustans
Lithophyllum tortuosum
Lomentaria articulata
Mastocarpus stellatus
Mesophyllum lichenoides
Nemalion helminthoides
Nitophyllum punctatum
Osmundea pinnatifida
Phyllophora crispa
Plocamium cartilagineum
Porphyra spp.
Pterocladiella capillacea
Pterosiphonia spp.
Rhodymenia pseudopalmata
Scinaia spp.

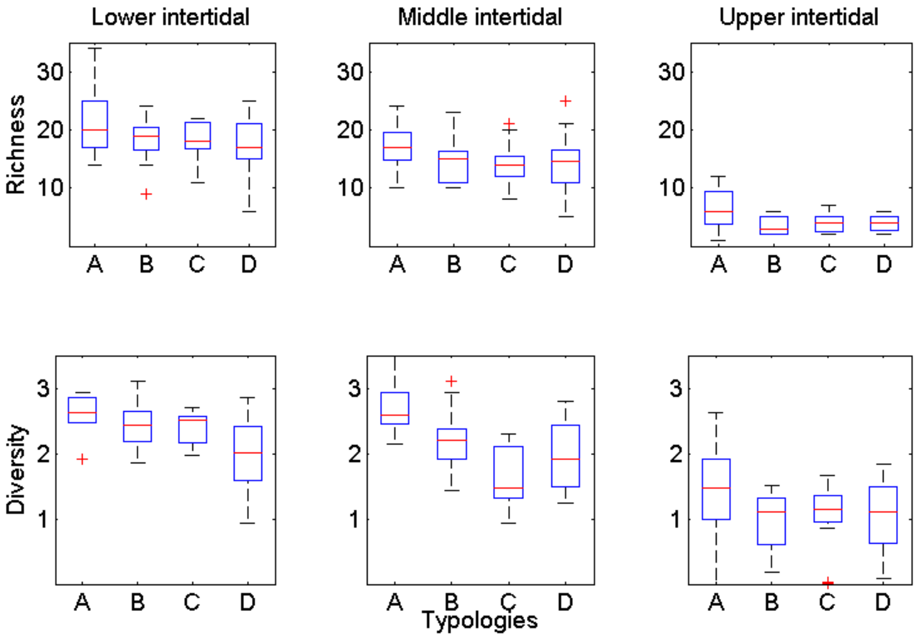


Figure 4.7. Box plots of species richness and the Shannon Wiener diversity for each typology (A: Lower Rias; B: Upper Rias; C: W Cantabric; D: E Cantabric). The middle line in the box is the median, and the lower and upper box boundaries mark the first and third quartiles. The whiskers are the largest and smallest observed values that are not statistical outliers (values more than 1.5 interquartile range), which are represented by crosses.

The MDS analyses confirmed the general agreement between the macroalgae distribution and physical groups in the lower and middle intertidal, which showed similar patterns (Figure 4.8). In these lower levels, two main groups could be identified, the Lower Rias (typology B) area on one side and the rest of the coast (typologies A, C and D) on the other. Therefore, the northwestern Galician area was a characteristic zone clearly differentiated from the rest of the coast. Moreover, the distribution of sampling sites located on the right area of the MDS graph showed a gradient from east to west, with W Cantabrian area (typology C) situated between the other two as a transitional area. This pattern was especially clear in the lower intertidal. By contrast, in the middle intertidal, typologies C and D were more mixed, showing that this belt was more or less similar all along the Cantabrian coast (from eastern Galicia to Basque Country). Finally, in the upper intertidal and supralittoral levels, there was no pattern related to physical typologies, reflecting the fact that the macroalgae found in these levels are sparse and not structural elements.

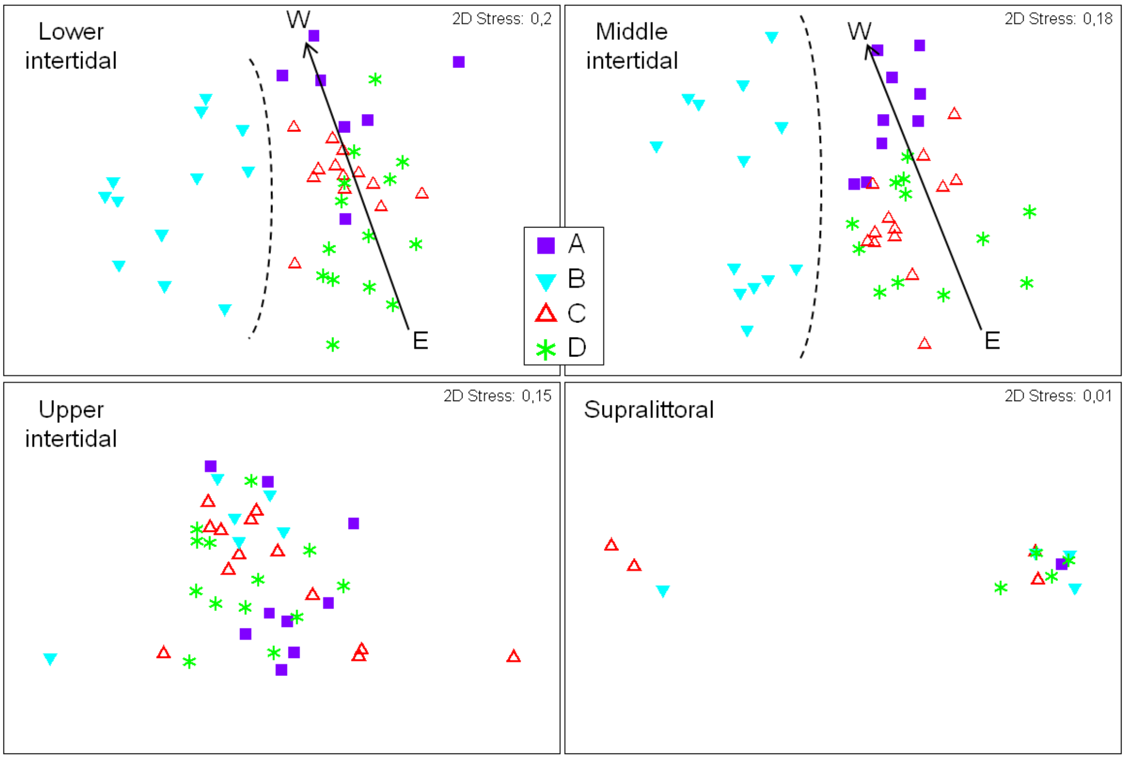


Figure 4.8. MDS analysis based on macroalgae distribution in each tidal level, from left top: lower intertidal, middle intertidal, upper intertidal and supralittoral. Transects are represented according to physical typologies.

The PERMANOVA results (Table 4.5) showed that the differences among typologies were significant. Two-way crossed analyses showed that there was a significant interaction between the typology and tidal range factors, which confirmed that the differences in macroalgae composition between typologies were not the same across different tidal levels. Thus, pair-wise comparisons of typologies have been performed within each level of tidal range to discern where the significant differences may lie. There was strong evidence ($p < 0.001$) to establish that most of the typologies differed from one another in the lower and middle intertidal. The only exception was found in the comparison between the Western and Eastern Cantabrian region (typologies C and D), for which the differences were weaker in the lower intertidal ($p < 0.01$) and not significant in the middle intertidal. Finally, there was no indication of differences between typologies within the upper intertidal, where differences were significant ($p < 0.01$) only between typologies A and B, while there were no significant differences at the supralittoral level. This confirms the result previously obtained in the MDS analysis, that the change in macroalgae distribution among typologies was lower or even absent at the higher levels.

Table 4.5. A. PERMANOVA results based on Bray-Curtis distances for macroalgae taxa data. Each test was conducted using 9999 random permutations; B. Pairwise comparisons of differences between typologies within each tidal level (A: Lower Rias, B: Upper Rias, C: West Cantabric, D: East Cantabric).

A. PERMANOVA				
Source of variation	Df	MS	Pseudo-F	*P* (perm)
Typology = T	3	8916	4.45	0.0001**
Tidal range= TR	3	29152	14.56	0.0001**
T x TR	9	4454	2.22	0.0001**
Res	131	2002		
Total	146			

B. Pairwise comparison			
Tidal range	Typologies	t	*P* (perm)
Lower intertidal	A, C	2.31	0.0002**
	A, B	2.91	0.0003**
	A, D	2.37	0.0001**
	C, B	3.51	0.0001**
	C, D	1.68	0.0092*
	B, D	3.41	0.0001**
Middle intertidal	A, C	2.58	0.0002**
	A, B	2.97	0.0001**
	A, D	2.44	0.0001**
	C, B	3.16	0.0001**
	C, D	1.54	0.0125
	B, D	3.00	0.0001**
Upper intertidal	A, C	1.34	0,0939
	A, B	1.57	0,0038*
	A, D	1.57	0,03
	C, B	1.10	0,2653
	C, D	1.07	0,3292
	B, D	1.52	0,0274
Supralittoral	A, C	0.92	0,6022
	A, B	0.68	1
	A, D	0.61	1
	C, B	1.03	0,3447
	C, D	0.85	0,7634
	B, D	0.78	0,7679

* $P < 0.01$; ** $P < 0.001$

According to SIMPER analysis, two taxa made a large contribution to the similarity of all the typologies and tidal levels: *Corallina officinalis/Ellisolandia elongata* and *Ulva* spp. (Table 4.6). By contrast, *Caulacanthus ustulatus* contributed to similarity along the whole middle intertidal study area, though not in any of the typologies within the lower intertidal. Specifically, the Lower Rias area (typology A) was dominated by *Ulva* spp. at both levels, accompanied by the non-native species *Asparagopsis armata* in the lower intertidal and by another opportunistic macroalgae, *Ceramium* spp., in the middle intertidal. The Upper Rias lower intertidal (typology B) was characterised by cold temperate species, such as *Mastocarpus stellatus*, *Saccorhiza polyschides, Chondrus crispus* and *Laminaria* spp. (*L. hyperborea* and *L. ochroleuca*). By contrast, *M. stellatus* and *Corallina officinalis/Ellisolandia elongata* were the codominant taxa in the middle intertidal of this area, along with another cold temperate species, *sensu* Lüning (1990), *Fucus vesiculosus*. In the lower intertidal of the Cantabrian coast, the taxa with the greatest contributions to similarity were *Bifurcaria bifurcata* and *C. officinalis/E. elongata*, though the former was clearly dominant in the western area (typology C) and the latter in the east (typology D). In both cases, these macroalgae were accompanied by *Stypocaulon scoparium.* Finally, the middle intertidal of the Cantabrian coast was dominated by *C. officinalis/E. elongata* throughout. For a more graphically representation of the different typologies and intertidal levels, in Figure 4.9 can be observed a type photograph (quadrat of 50 x 50 cm) of each combination.

Table 4.6. Taxa within lower and middle intertidal levels that contributed to similarity in each typology, according to SIMPER analysis results. The lower cut off is 90% of cumulative contributions.

Lower intertidal			
A	B	C	D
Ulva spp. (45.2%)	*M. stellatus* (33.2%)	*B. bifurcata* (40.68%)	*C. officinalis/E. elongata* (46.7%)
A. armata (21.0%)	*C. acicularis* (18.5%)	*C. officinalis/E. elongata* (19.2%)	*B. bifurcata* (18.0%)
C. officinalis/E. elongata (7.2%)	*C. officinalis/E. elongata* (16.7%)	*Ulva* spp. (17.7%)	*S. scoparium* (14.7%)
S. scoparium (5.2%)	*S. polyschides* (11.9%)	*S. scoparium* (11.4%)	*Ulva* spp. (8.5%)
Ceramium spp. (3.8%)	*Ulva* spp. (5.2%)	*Ceramium* spp. (3.2%)	*L. incrustans* (3.5%)
F. rufolanosa (3.5%)	*C. crispus* (3.7%)		
C. tomentosum (3.2%)	*Laminaria* spp. (2.3%)		
B. bifurcata (2.9%)			

Middle intertidal			
A	B	C	D
Ulva spp. (35.2%)	*C. officinalis/E. elongata* (29.2%)	*C. officinalis/E. elongata* (68.5%)	*C. officinalis/E. elongata* (66.0%)
Ceramium spp. (19.5%)	*M. stellatus* (26.5%)	*Ulva* spp. (15.1%)	*C. ustulatus* (14.1%)
C. officinalis/E. elongata (11.3%)	*F. vesiculosus* (14.9%)	*Ralfsia verrucosa* (4.6%)	*Ulva* spp. (9.7%)
C. acicularis (10.4%)	*C. acicularis* (8.7%)	*C. ustulatus* (3.0%)	*S. scoparium* (3.2%)
C. ustulatus (7.6%)	*Ulva* spp. (5.5%)		
B. bifurcata (6.1%)	*C. ustulatus* (2.9%)		
	B. thuyoides (2.7%)		

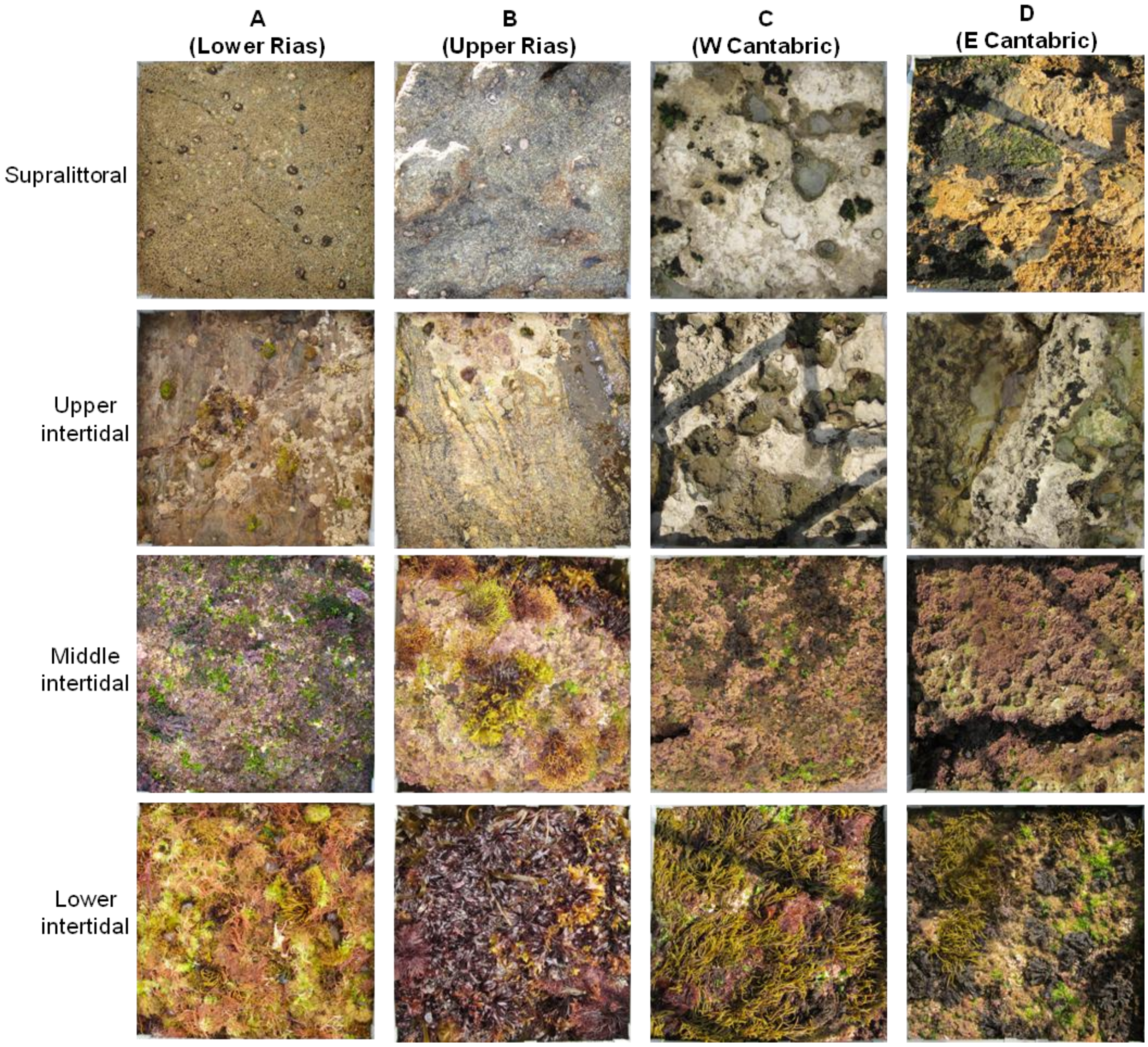


Figure 4.9. Type photographs (quadrats of 50 x50 cm) of each typology and intertidal level.

The macroalgae taxa that contributed the most to dissimilarity among typologies according to SIMPER analysis (not shown) are represented on the SOM that was previously trained with physical data (Figure 4.10). Each small map corresponding to a taxon could be compared to or superimposed on the maps representing the distribution of physical variables and k-means groups in Figure 4.6. As can be observed, *Boergeseniella thuyoides, Chondrus crispus, Cystoseira baccata, Himanthalia elongata, Pterocladiella capillacea* and *Saccorhiza polyschides* had greater cover in the northwestern Iberian Peninsula coast (typologies A and B). This area was related with the lowest maximum SST. Regarding these typologies separately, the Lower Rias area (map units on the right-bottom area of the SOM) showed the highest percentage of *Asparagopsis armata* and its tetrasporophitic phase, *Falkenbergia rufolanosa, Ceramium* spp., *Codium tomentosum* and *Ulva* spp. These map units were characterised by the highest radiation and minimum SST. By contrast, the Upper Rias coast (left-bottom area of the SOM) presented higher cover of *Chondracanthus acicularis, Laminaria* spp., *Mastocarpus stellatus* and *Osmundea pinnatifida,* corresponding to the largest values of wave height. Finally, the Western Cantabric area (top of the map) was related to higher cover of *Bifurcaria bifurcata* and *Stypocaulon scoparium*. With respect to abiotic variables, in this area the lowest radiation, the minimum SST and the maximum tidal range values were found. Apart from those findings, the family Corallinaceae (*Corallina officinalis/Ellisolandia elongata, Litophyllum incrustans* and *Litophyllum tortuosum*) was present in almost all map units of the SOM, showing a wide distribution.

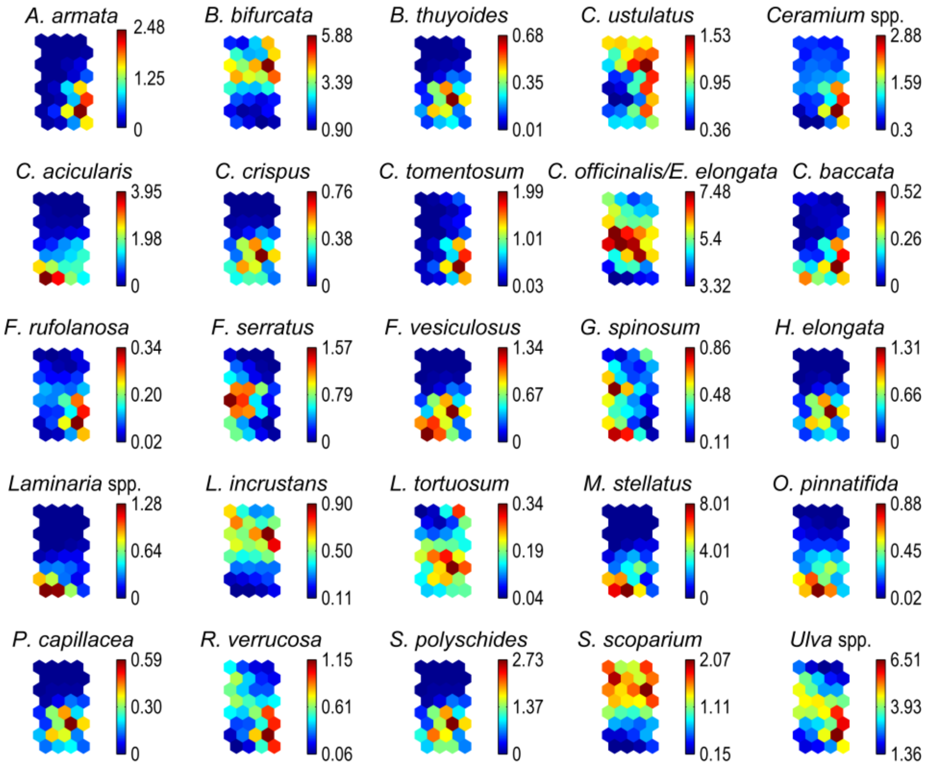


Figure 4.10. Visualisation of average percentage cover of taxa on the SOM-trained data with physical variables, with visualisation in a blue (low percentage cover) to red (high percentage cover) scale.

4.4. Discussion

Overall, this paper presents a successful downscaling methodology for accurately identifying characteristic environmental conditions and species distributions at a regional scale, based on a previous classification system for the entire NE Atlantic biogeographic region (Ramos et al., 2012; Ramos et al., 2014). Despite this general statement, the ecological interpretation of the classification systems for predicting the distributions of species or habitats is a good starting point for discussion of its applicability to management and conservation of marine ecosystems. The inconsistent scales of variation found in physical and biological variables, the homogeneity in their quantification, the specificity of interactions and the synergies among these factors are among the most frequent criticisms to this type of approach.

Some questions about the physical classification and the biological validation arise from debate regarding the suitability of a classification system. First, the selection of the most representative physical variables is a crucial factor. These variables are the basis of the classification and have to be quantified in a homogenous way and with the level of precision appropriate to the scale. Different approaches previously developed in other regions (Connor et al., 2004; Bouma et al., 2005; Mount et al., 2007; Madden et al., 2009) agree on the use of some physical descriptors, although there are differences in how to express them. For example, it seems clear that the energy of the system is a necessary variable in this type of work, but classification schemes may use the expression in terms of waves, the degree of exposure, the fetch, or the shear stress, etc. The wave energy variable was derived from remote sensing for the NE Atlantic (Ramos et al., 2012) and numerical modelling data in the Bay of Biscay, according to the two hierarchical scales. Furthermore, some variables may only have ecological meaning at a certain scales. For instance, the salinity is a variable included in the classification carried out in the NE Atlantic, but not at the present scale because it varies in a short range along the Bay of Biscay coastal waters.

Another important element that must be established is the required number of variables, their type and how to ensure the absence of redundancies between them. Along the North Iberian Peninsula the most determinant variables in the different distribution of species seem to be water temperature and exposure to wave action, although it is the combination of the six selected indicators what properly classifies the coast. Some variables commonly employed in coastal and marine classification systems have not been included in the present study, such as nutrients and substrate (e.g., Roff and Taylor, 2000; Connor et al., 2004; Valentine et al., 2005). At the Bay of Biscay, the most significant nutrients concentration gradients are strongly related to sea surface temperature (Lavin et al., 1998; Alvarez et al., 2008), but there is no standardized and reliable data series large enough to cover the entire study area. At the same time, information about the substrate is not available at the required level of definition, although there are some global GIS layers of sea-bed substrate and geology (e.g., European Marine Observation and Data Network, EMODnet). In any case, information about sandy or rocky substrates will not lead to a significant difference in this work because the objective is to classify coastal waters for rocky macroalgae; therefore, rocks are the relevant substrate. Further downscaling analyses at the local scale will consider the integration of geomorphological factors (coastal orientation, coastal morphology, slope of the shore, etc.).

An additional point to be considered is the type of information in terms of both the availability of historical data and the medium-term perspective to obtain the relevant data at finer scales of analysis with the required accuracy and precision. For instance, two opposite proposals can be analysed: the classification of Dutch coasts, ZES1, (Bouma et al., 2005) and the Europe-wide EUNIS classification (Davies et al., 2004). The first requires in situ salinity measurements for a year and the maximum linear flow velocity during a half tide and the high orbital velocity tides. By contrast, in EUNIS, the classification criteria used to establish the limits for each variable are not specified. Instead, variables such as exposure to wave action are analysed from a strictly qualitative viewpoint. To perform this challenging task, the interaction among experts of different disciplines (e.g., ecology, oceanography, meteorology) may substantively improve the development of new ecologically sound physical variables that are suitable for classifications at different scales. Moreover, the availability of data at finer temporal scales (e.g., hourly data of SST) may facilitate hypothesis testing on ecological interactions.

Likewise, the specific spatial domains must first be delimited to ensure that the physical data series properly describe the main processes within the study area. The suitability of the procedure applied in the present study to characterise the physical environment (i.e., variables calculated through remote sensors at points 150 m deep each 20 km) has been demonstrated, showing a similar pattern to the results obtained from in situ measurements (Casares, 1987; Valencia et al., 2004; Alvarez et al., 2008). However, the use of satellite sensors and numerical modelling allows easy quantitative measurements of physical variables and provides continuous and uniform information along the coast. In addition, including a numerical reanalysis to quantify wave height improves the temporal and spatial coverage of the record (data available every hour from 1948 onwards and at a spatial resolution of 0.1°) over the data that are obtained by satellite sensors, calibrated and corrected (Reguero et al., 2012). The high availability of data raises the possibility of using more specific wave variables in future approaches, such as the bottom shear stress or the frequency of extreme events, which have greater explanatory potential for the important interaction between wave energy and organisms (Hiscock, 1983; Gaylord, 1999).

Once all the information is available, a different problem arises: the interpretation of results by means of statistical tools. Despite common doubts related to the introduction of mathematical artefacts for this type of combined analyses, they may provide an objective way to detect general trends in the distribution of areas with similar characteristics. The development of a classification system is highly dependent on the choice of the statistical tools and statistical parameters that ultimately determine the configuration of groups. The analyses must be in accordance with our objective of finding statistically what we are not able to recognise from the raw data. This paper proposes a protocol that reduces the level of subjectivity in the final classification. Decision rules for the classification of sites were provided: first, the use of the heuristic formula; then, the quantisation and topographic errors for the selection of the number of units of the SOM map; and, finally, the Davies-Bouldin index for the establishment of k-means groups. In addition, the self-organizing map tool has shown its capacity to deal with complex environmental data, and it is a suitable technique to investigate, model, and control many types of water systems and processes (Kalteh et al., 2008). In fact, some review articles have emphasised the efficient and high performance of neural networks and SOM for ecological patterning compared with conventional statistical methods (c.f. Gevrey et al., 2003).

The most important point is that our statistical classification has a real ecological meaning in terms of agreement with the specific objective and the study scale. The objective of the present study was not to detect differences in small capes or bays, which could be studied in further works, as previously mentioned, but to analyse the general variation in conditions along the N and NW Spanish coast. Because of this, all locations selected for the biological validation are exposed to wave action, in the same way that they could have all been sheltered. With respect to the groups generated, the first group, Lower Rias, extends to Cape Finisterre. This division is justified because the coastline abruptly changes its orientation from north-south to east-west, with the modification of some key environmental variables involved. In addition, this area has unique geomorphological features due to the presence of rias and several islands in front of the coast. Furthermore, the most marked difference between the Upper Rias and West Cantabric typologies is the intensity and frequency of the upwelling phenomena, which is much higher in the Atlantic than in the western part of the Cantabrian coast (Alvarez et al., 2010). This process causes a sharp decline in temperature during spring-summer and an increase in the available nutrients, which modifies important environmental conditions for organisms (Fraga, 1981). The West Cantabric coast seems to be a transitional area around Peñas Cape, separating the eastern and western study area into two very different zones. Finally, the East Cantabric typology is very different from the rest because it is located in the inner part of the Bay of Biscay, where waters are more confined, presenting unique hydrodynamic and temperature characteristics (Lavin et al., 1998). This classification of the coast would fit in the Level 3 of the EUNIS hierarchical classification, where intertidal habitats are differentiated according to the exposure to wave action. In a general way, Lower and Upper Rias are comparable to EUNIS group A1.1 (High energy littoral rock) and West and East Cantabric are analogous to EUNIS group A1.2 (Moderate energy littoral rock). In any case, the group A1.4 (Features of littoral rock) can be found in all the typologies, what shows the different approach and scale applied in both classifications.

Nevertheless, the actual ecological sense of the physical classification is ultimately conferred by its contrast versus the distribution of some biological element (e.g., habitat type, community, species, etc.) for which the environmental variables were selected. Thus, it is evident that the physical classification requires a biological validation in accordance with the study objective and scale. The most frequent problem used to be the lack of standarised information for those elements along the spatial domain, mainly for studies over large areas (e.g., NE Atlantic, Bay of Biscay, etc.). In these cases, several solutions are now possible, such as the use of specific target areas located along ecotones (i.e., borders between physical classes), the selection of indicator species instead of the whole community, or the use of qualitative data (e.g., presence/absence). Ramos et al. (2014) used presence/absence data to validate the physical classification at a European scale. However, at regional scales (i.e., subtypological variants inside each biotype), this type of information is usually not sufficiently precise. Therefore, the quantitative data that were used in this work, which were homogenous and standardised in both in time and in space, are relevant because they properly characterise and support the typologies at a regional scale.

Moreover, in regard to the method applied to obtain macroalgae cover, the combined technique of identification in situ and quantification through photographs presents three main advantages. First, the previous identification of taxa through direct observation in the field allows the recognition of organisms hidden by taller species, which would be more difficult at a later time in photos. Second, the software photograph analyses lend objectivity to these data because there is no observer estimation. Finally, photographs provide the added benefit of permanent visual records, which can later be revisited for additional information in the images (Parravicini et al., 2009).

The analysis of taxa cover data allows us to confirm the biological integrity of the typologies and to characterise them according to macroalgae distribution. Regarding biodiversity, the western area (Lower Rias typology) showed the greater species richness and diversity, where the characteristic kelps of cold-temperate waters are found in exposed coasts (Bárbara et al., 2005). In general, both richness and diversity indices decrease from west to east, reaching the lower values in the inner part of the Bay of Biscay (East Cantabric typology). By contrast, there was remarkably high cover of opportunistic algae (e.g., *Ulva* spp.) in the Lower Rias typology. This peculiarity is most likely caused by the natural enrichment in nutrients of the area due to positive estuarine circulation that concentrates nutrients and to periodic upwelling events that occur in spring and summer (Álvarez-Salgado et al., 1993). Moreover, there are nutrient inputs from the dense population living in the surrounding areas, which makes these zones susceptible to eutrophication (Villares and Carballeira, 2003).

The biological validation should also take into account the variability along the altitudinal gradient on the shore. In contrast to the biogeographical gradients, at the regional and local scales, the macroalgae distributions at different heights can help to explain certain patterns of longitudinal variability related to the specific typologies. Differences in species composition among the four physical typologies have been found in the lower and middle intertidal levels, which was expected, taking into account the characteristic macroalgae zonation models (Lewis, 1964; Stephenson and Stephenson, 1972; Lüning, 1990). The distinction between typologies C and D is not very clear in the middle intertidal because *Corallina officinalis/Ellisolandia elongata* is the dominant taxa all along the coast of the Bay of Biscay. However, in the lower intertidal there is a transition from a brown algae belt (dominated by *Bifurcaria bifurcata*) to a red one (dominated by *C. officinalis/E. elongata*) towards the east, which marks the difference between the two typologies. By contrast, the dominance of fauna species in the higher intertidal underscored the limited contribution of macroalgae to the validation of physical typologies at this level. At the same time, the upper zone is more sensitive to local phenomena (e.g., aerial exposure, biological interactions, etc.) than geographic gradients (Anadón, 1983).

Considering the longitudinal distribution of species along the study area, the data obtained in this work reflect both the general pattern described by other authors from local surveys carried out through the last century (Fischer-Piette, 1955, 1963; van den Hoek, 1975; Anadón and Niell, 1981; Anadón, 1983; Díez et al., 2003; Borja et al., 2004; Gorostiaga et al., 2004) and the more recent changes in macroalgae distributions in certain coastal areas. In brief, the macroalgae species of the Upper Rias typology are similar to those of the northern European latitudes (Lüning, 1990; Bárbara et al., 2005). The environmental conditions in this area, characterised by high wave heights and low maximum temperatures, are thought to drive this pattern because they are similar to those at latitudes farther northern. By contrast, the East Cantabric typology presents intertidal vegetation with an evident southern character. These differences are based on the scarcity or absence of several Ochrophyta (as *Fucus* spp., *Himanthalia elongata*, *Laminaria* spp., *Saccorhiza polyschides*) and other cold-water species (*Chondrus crispus, Mastocarpus stellatus*) on this coast. At the same time, there is a known phenomenon in the study area that should be considered, the significant shift in the distribution limits of cold-temperate species eastwards and westwards between San Vicente de la Barquera (Cantabria) and Cangas de Foz (Lugo) in recent decades (Fischer-Piette, 1963; Anadón and Niell, 1981; Anadón, 1983). Since the 1980s, there has been a westward retreat of kelps (Fernández, 2011) and Fucales (Duarte et al., 2013) due to rising superficial seawater temperatures during summer (Voerman et al., 2013), a situation that is also reflected by the classification developed. Thus, along typology C, there is a biogeographic boundary that shows the transitional character of this area and the difficulty posed by an attempt to define borders in such a continuous natural environment.

Finally, all of these results show the importance of a classification system as a tool to predict the most conspicuous trends in macroalgae distribution. The information provided could be useful to test hypotheses about climate change. In this area, some studies on the distribution of species in response to the possible influence of climate change have already been developed at local scales (Díez et al., 2012; Martínez et al., 2012). Using the resources proposed in this work, it would be possible to carry out a more global study at a regional scale to predict trends under specific climate change scenarios.

In conclusion, the downscaling methodology developed in this work to classify coastal waters can be considered an appropriate tool for recognising ecological typologies at a regional scale. Our ability to identify environmental conditions and species distributions with the classification system shows the suitability of adapting methodologies to specific spatial requirements. The specific results along the study area divided the N and NW Spanish coast into four typologies: Lower Rias (typology A, from the Portuguese border to Finisterre Cape), Upper Rias (typology B, from Finisterre Cape to Ria de Vivero in Lugo), West Cantabric (typology C, from Ria de Vivero to Peñas Cape) and East Cantabric (typology D, from Peñas Cape to the French border). The ecological meaning of these typologies has been confirmed for tidal levels where seaweeds are a structural element (lower and mid intertidal). Regarding communities composition, Lower Rias typology is dominated by *Asparagopsis armata* and *Ulva* spp. in the lower intertidal, and *Corallina officinalis/Ellisolandia elongata*, *Ulva* spp, and *Ceramium* spp. in the middle intertidal; Upper Rias is characterised by *Mastocarpus stellatus* and *Chondracanthus acicularis* (lower intertidal), and *C. officinalis/E. elongata, M. stellatus* and *Fucus vesiculosus* (middle intertidal); in the West Cantabric *Bifurcaria bifurcata* is the dominant taxa in the lower intertidal and *C. officinalis/E. elongata* in the middle intertidal; while, finally East Cantabric is dominated by *C. officinalis/E. elongata* in both levels, accompanied by *B. Bifurcata* in the lower intertidal and by *Caulacanthus ustulatus* in the middle intertidal. Specifically, there is a clear difference between the Upper Rias typology and the rest of N and NW Iberian Peninsula coast, showing a gradient previously reported in the literature. Thus, this ecologically meaningful classification intends to remove any ambiguity in the use of subjective classification schemes, ensuring that results are reliable and provide a sound foundation for assessment criteria and the accurate diagnosis of a state of conservation that, ultimately, contributes to sustainable management.

Chapter V

The role of geomorphology in macroalgae distribution at local scale

Chapter V. The role of geomorphology in macroalgae distribution at local scale

This chapter is an edited version of the research article submitted for publication to the journal Estuarine, Coastal and Shelf Science, by Ramos, E., Díaz de Terán, J.R., Puente, A., Juanes, J.A., with the title "The role of geomorphology in the distribution of intertidal rocky macroalgae in the NE Atlantic region".

Abstract

It is known that rocky macroalgae distribution depends on several abiotic factors, but little attention has been given to geomorphological influences. This paper analysed the relation between geomorphological variables (active processes, coastal morphology, coastal orientation and lithology) and rocky intertidal macroalgae species at a local scale. Thirteen sites were sampled along the coast of Cantabria (North Spain) in order to obtain covers of macroalgae species. Multivariate analysis and logistic regression were applied, predicting the probability occurrence of macroalgae species as a response to the predictor geomorphological variables. Our results showed that coastal morphology and coastal orientation were the principal geomorphological factors explaining the structure of macroalgae communities. The most significant differences in substrate preferences were found between *Bifurcaria bifurcata* that appears in wave-cut platforms oriented towards the east, and *Corallina officinalis/Ellisolandia elongata* and *Gelidium spinosum*, which are found in cliffs oriented towards the North and West. Thus, these geomorphological variables help to characterise species distribution, even if their predictive value is still limited, possibly due to other factors influencing macroalgae.

5.1. Introduction

The successful protection and management of marine diversity, the assessment of anthropogenic impacts and the restoration of altered ecosystems rely largely on understanding the processes and factors that structure biological assemblages (Chapman, 1999). Thus, relationships between environmental factors and organisms need to be explored in order to recognise the key agents that determine the composition of communities and the distribution of species.

Several abiotic and biotic factors determine the distribution and structure of coastal benthic communities, depending on the main drivers of ecological processes and patterns at a spatial scale (Levin, 1992). At a local scale, factors such as geomorphological characteristics and vertical height, seem to affect species distribution (Schoch and Dethier, 1996; Díez et al., 2003; Chappuis et al., 2014). Focusing on geomorphological features, different variables may affect the sessile assemblages in different ways. The aspect (direction of the surface floor), slope and texture of the surface may cause differences in drainage, evaporation, sedimentation and shade, modifying the characteristic patterns of the intertidal zone (Lobban et al., 1985; Rinne et al., 2011). Roughness may also influence composition through indirect effects on herbivore activity (Jenkins et al., 2008). The type of substratum affects the retention of heat and water, which makes algae grow or survive better (McGuinness and Underwood, 1986; McGuinness, 1989), causing differences among assemblage structures and the covers of individual taxa of algae (Green et al., 2012). On the other hand, substratum nature could also affect turbidity, as it is high when the substrate is extremely fine (Dixon and Irvine, 1977). In general, the agents that cause the differences in assemblages can change in their intensity due to the geomorphology of the rocky coast (Bird, 2008).

In spite of the important role played by geomorphological characteristics in explaining patterns in the structure of rocky communities (e.g., Cerrano et al., 1999; Bavestrello et al., 2000), relatively little attention has been paid to the study of these types of interaction, except for those focused on the settlement of larval stages of fauna species depending on rock type (Fischer, 1981; Anderson and Underwood, 1994; Schiaparelli et al., 2003). Although seaweeds are among the most obvious and ecologically important components of rocky shore communities worldwide (Lubchenco et al., 1991), until now little has been known about the influence of substrate mineralogy and geomorphology on their distribution.

Given the important synergies found between geomorphology and macroalgae communities, a detailed study should be performed in order to test the specific effect of each geomorphological variable on rocky intertidal macroalgae species. Taking into account that the potential effects of geomorphology occur at a local scale, and in order to avoid noise caused by other abiotic factors, it will be appropriate to carry out such a study in a homogenous area based on meteo-oceanographic conditions. For this reason, the coast of Cantabria (North Spain) may be an optimal zone for this study, as it is considered a unique environmental typology at both European and regional scales (Ramos et al., 2012; Ramos et al., 2014; Ramos et al., in press). In addition, this coast shows geomorphology variability, allowing us to study the influences of different geomorphological factors.

This paper is aimed at testing whether geomorphological features influence the distribution and structure of rocky intertidal macroalgae communities. More specifically, the objective was to determine which geomorphological factors cause differences in macroalgae communities, at which level of community organisation these differences are caused, and the main species affected. This detailed study of seaweeds and their environment contributes to understanding about the ecology and distribution patterns of these communities and, consequently, to the assessment and conservation of marine ecosystems.

5.2. Methodology

5.2.1. Study area

This study was carried out on the coast of Cantabria, approximately 200 km long, located in the North of the Iberian Peninsula (NE Atlantic). The Cantabrian Coast is divided into a series of pocket beaches and small inlets isolated between rocky headlands. Most of the coastline has quite stable cliffs, as they are formed by compact rocks, although some show clear signs of retreat (Rivas and Cendrero, 1992). The composition of the substrate is mainly massive and stratified cretaceous or carboniferous limestone, with some areas where Palaeozoic quartzite can be found. Waves on the Bay of Biscay approach mostly from the Northwest with a mean significant wave height (Hs) of 1 m and a typical winter storm significant wave height of Hs ≈ 5 m. The tides are semi diurnal with a mean tidal range of 3 m and a spring tidal range of 5 m.

Within the intertidal area of the Cantabrian coast two clear fringes can be distinguished according to macroalgae communities: the middle intertidal, dominated by *Corallina officinalis/Ellisolandia elongata* and accompanied by calcareous encrusters, *Caulacanthus ustulatus, Ceramium* spp., *Chondracanthus* spp., *Osmundea* spp., etc., and the lower intertidal, dominated by *Bifurcaria* spp. and accompanied by *Stypocaulon scoparium, Codium* spp., *Cladostephus* spp., various red small folioses, Champiaceae, etc. (Fernández and Niell, 1982; Anadón, 1983; Guinda et al., 2008; Ramos et al., in press).

5.2.2. Collection of data

In order to obtain biological data, field work was carried out during spring tides in April 2011 and May and June 2012 in 13 sites located along the coast of Cantabria (Figure 5.1). We selected sites that covered as much geomorphological variability as possible in the study area. At each site, three transects perpendicular to the coast were selected, which were separated by 50-100 m and had a coverage of macroalgae greater than 50% (see detailed information about transects in Table 5.1). A stratified sampling was carried out taking into account the characteristic zonation pattern of the study area previously described. In this way, each transect was divided into two zones: 1) Lower intertidal (belt of brown algae) and 2) Middle intertidal (belt of red algae). Three sampling stations of 50 x 50 cm were distributed at equal distances in each area. As such, 177 quadrats were sampled, 86 in the lower intertidal and 91 in the middle. Covers of macroalgae species were obtained by photo analyses as described in Ramos et al. (in press) because this is a good approach to relate physical factors to species distribution.

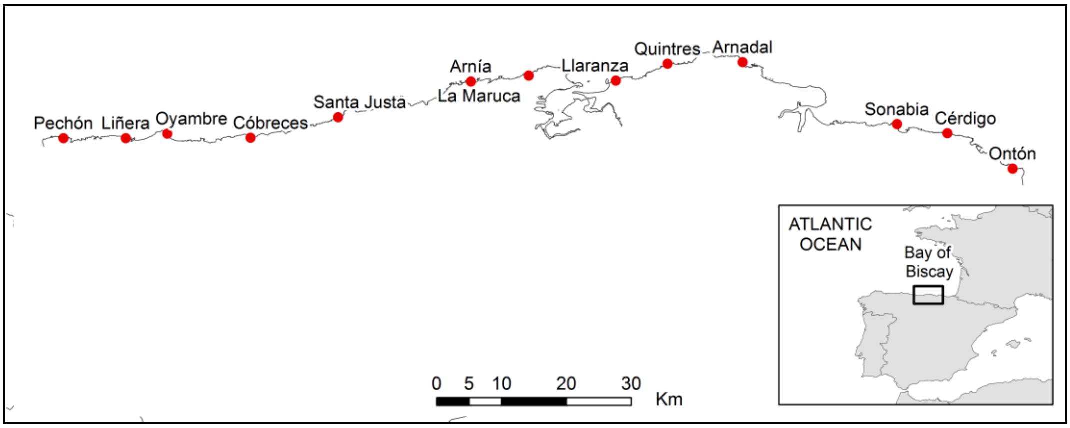
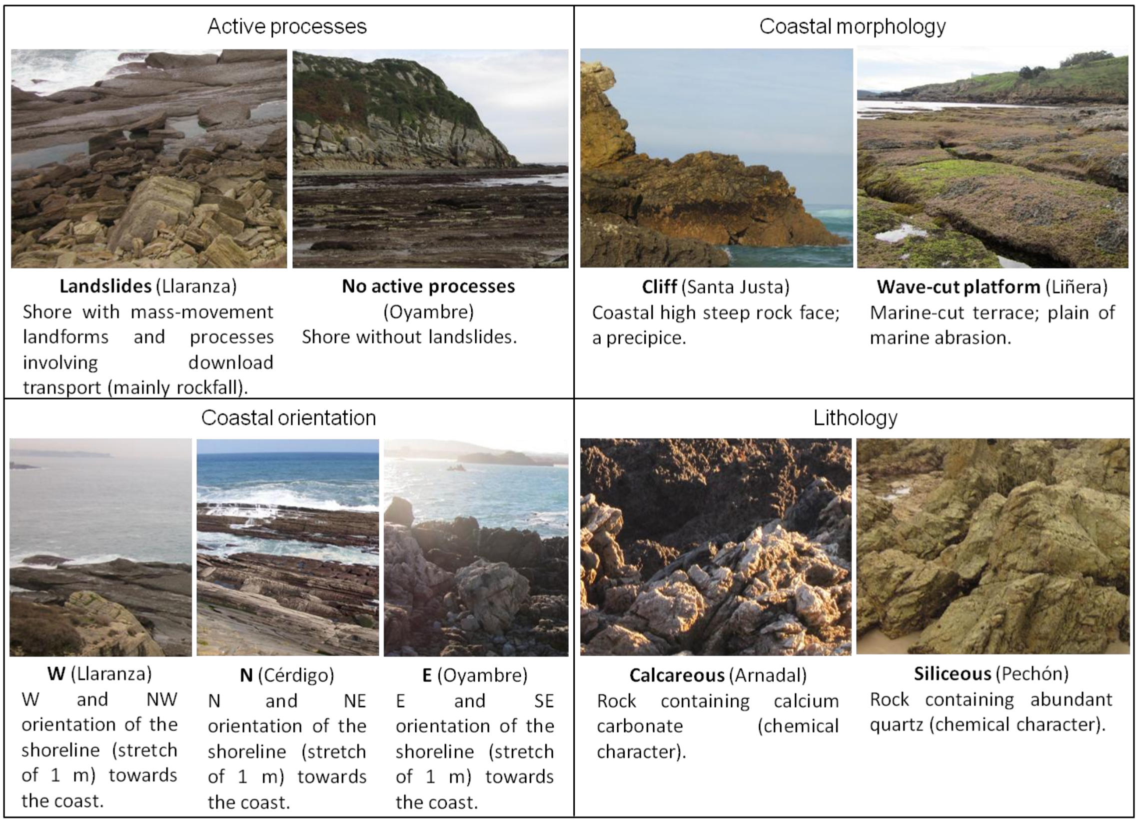


Figure 5.1. Location of the 13 sampling sites along the coast of the Cantabria region (Bay of Biscay).

Table 5.1. Georeference, direction, length and altitude of transects.

Site	Transect	Latitude (N)	Longitude (W)	Length (m)	Altitude (m)
Arnadal	1	42°14'6.64''	8°53'59.45''	5.3	0.9
	2	42°14'3.41''	8°53'59.72''	5.5	-
	3	42°24'48.94''	8°52'18.65''	5.5	-
Arnía	1	42°24'49.47''	8°52'20.65''	35.5	0.5
	2	42°25'57.06''	8°52'28.54''	46.7	1.1
Cérdigo	1	42°25'58.41''	8°52'31.49''	5	1.1
	2	42°31'23.80''	9°2'30.00''	7.5	0.4
	3	42°31'24.62''	9°2'28.49''	7.4	0.9
Cóbreces	1	42°31'29.17''	9°2'29.35''	24.2	0.8
	2	43°4'27.27''	9°14'58.47''	8	2.7
La Maruca	1	43°4'27.27''	9°14'58.47''	45.3	4.0
	2	43°11'41.10''	9°7'10.46''	35	3.4
Liñera	1	43°17'32.99''	8°43'16.08''	31.2	1.1
	2	43°17'32.56''	8°43'15.21''	31.5	0.9
	3	43°18'50.07''	8°34'8.71''	23.15	1.8
Llaranza	1	43°18'49.01''	8°34'7.81''	12.6	1.1
	2	43°18'47.46''	8°34'6.87''	34	1.8
Ontón	1	43°30'37.45''	8°19'40.78''	10.4	0.8
	2	43°30'36.26''	8°19'40.48''	11.2	1.3
	3	43°30'33.77''	8°19'43.11''	6.3	1.3
Oyambre	1	43°37'47.31''	7°19'56.92''	79	2.8
	2	43°37'46.19''	7°19'57.62''	29.3	2.1
Pechón	1	43°37'43.74''	7°19'58.34''	17.8	0.8
	2	43°34'16.77''	6°56'20.46''	14	0.7
	3	43°34'15.72''	6°56'20.18''	15.2	1.3
Quintres	1	43°34'14.09''	6°56'19.78''	7.4	0.8
	2	43°33'35.25''	6°23'46.63''	18	1.9
	3	43°33'31.00''	6°23'30.73''	10.5	0.7
Santa Justa	1	43°33'59.66''	6°11'29.40''	8	1.5
	2	43°33'58.70''	6°11'29.08''	7	2.7
Sonabia	1	43°33'57.90''	6°11'28.89''	11.4	1.7
	2	43°36'42.04''	5°46'50.86''	4.5	1.8

Geomorphological characteristics of the sampling sites were initially obtained by an analysis of the corresponding 1:50000 Geologic Maps (Geological and Mining Institute of Spain, IGME). In some cases, additional fieldwork was carried out to confirm uncertain data. For each sampling site, four geomorphological variables were considered: active processes, coastal morphology, coastal orientation and lithology, according to the definitions of the categories in Figure 5.2.



Active processes

Landslides (Llaranza)
Shore with mass-movement landforms and processes involving download transport (mainly rockfall).

No active processes (Oyambre)
Shore without landslides.

Coastal morphology

Cliff (Santa Justa)
Coastal high steep rock face; a precipice.

Wave-cut platform (Liñera)
Marine-cut terrace; plain of marine abrasion.

Coastal orientation

W (Llaranza)
W and NW orientation of the shoreline (stretch of 1 m) towards the coast.

N (Cérdigo)
N and NE orientation of the shoreline (stretch of 1 m) towards the coast.

E (Oyambre)
E and SE orientation of the shoreline (stretch of 1 m) towards the coast.

Lithology

Calcareous (Arnadal)
Rock containing calcium carbonate (chemical character).

Siliceous (Pechón)
Rock containing abundant quartz (chemical character).

Figure 5.2. Examples and description of the categories of geomorphological variables corresponding to different sampled sites.

5.2.3. Data analysis

The relation between geomorphological features and intertidal macroalgae was analysed at three levels of organisation: community descriptive parameters, assemblage composition and species preferences. First, specific richness (S) and Shannon-Wiener diversity (H' log2) were calculated based on species cover in each sample. A one-way ANOVA test was carried out to prove whether differences in these indexes between geomorphological categories were statistically significant. Levene's test for equality of variances and a histogram plot to verify the normal distribution of the data had been performed. If variance was not homogenous after logarithmic transformation, a Kruskal-Wallis test was carried out.

As a second step, an ANOSIM test was applied to detect significant differences in assemblage composition among the geomorphological variables. Prior to the multivariate analysis, cover data was previously square root transformed and the similarity matrix was calculated using Bray-Curtis similarity coefficient.

Finally, the response of individual species to geomorphological variables was modelled. A preselection of the species was made through a SIMPER analysis. Then, a logistic model was carried out taking into account the categorical nature of the parameters studied in this paper (Tom et al., 2002; Guanche et al., 2013). This statistical method measures the fitting quality by comparing the deviance ratio (Δdev) and the chi-square distribution ($\chi 2$). Assuming a confidence level $\alpha=95\%$, if $\Delta\text{dev} > \chi^2_{0.95\%,\Delta\text{dev}}$, the fitting quality of the parameter was significant. Once the parameters estimated for the models are known, the predicted probabilities *p* of the significant fittings were represented according to four categories: absent, low (0-33% probability of occurrence), medium (33-66% probability of occurrence) and high (66-100% probability of occurrence). Thereby, the graphical representation allowed us to visualise the probability of occurrence of each species, based on its relative abundance, according to geomorphological variables.

Assuming shore height as the main influencing factor in the distribution of species at this scale (Wallenstein and Neto, 2006; Chappuis et al., 2014), separate analyses were performed for each tidal level (lower and middle intertidal). Statistical analyses were carried out using the Statistica 6.0 program (ANOVA analysis), the package PRIMER-E (v.6 + PERMANOVA) (ANOSIM and SIMPER analyses) and Matlab R2011b (logistic model).

5.3. Results

A total of 65 different macroalgae taxa were recorded, 62 in the lower intertidal and 53 in the middle one (taxa list in Table 5.2). The most widely represented phylum was Rhodophyta with a total of 47 taxa, followed by Ochrophyta with 14 and Chlorophyta with 4.

Table 5.2. Taxa list of identified intertidal rocky shore macroalgae.

Chlorophyta	Rhodophyta	Rhodophyta (2)
Cladophora rupestris	*Acrosorium ciliolatum*	*Gymnogongrus crenulatus*
Codium adhaerens	*Ahnfeltia plicata*	*Halopithys incurva*
Codium tomentosum	*Apoglossum ruscifolium*	*Halurus equisetifolius*
Ulva spp.	*Asparagopsis armata*	*Heterosiphonia plumosa*
	Boergeseniella fruticulosa	*Hildenbrandia rubra*
Ochrophyta	*Boergeseniella thuyoides*	*Hypoglossum hypoglossoides*
Bifurcaria bifurcata	*Calliblepharis ciliata*	*Jania rubens*
Cladostephus spongiosus	*Caulacanthus ustulatus*	*Laurencia obtusa*
Colpomenia peregrina	*Ceramium* spp.	*Lithophyllum incrustans*
Cystoseira baccata	*Champia parvula*	*Lithophyllum tortuosum*
Cystoseira tamariscifolia	*Chondracanthus acicularis*	*Lomentaria articulata*
Dictyopteris polypodioides	*Chondracanthus teedei*	*Mastocarpus stellatus*
Dictyota dichotoma	*Chondria coerulescens*	*Mesophyllum lichenoides*
Ectocarpales	*Chondrus crispus*	*Nemalion helminthoides*
Leathesia marina	*Chylocladia verticillata*	*Nitophyllum punctatum*
Padina pavonica	*Corallina officinalis/Ellisolandia elongata*	*Osmundea pinnatifida*
Ralfsia verrucosa	*Cryptopleura ramosa*	*Peyssonnelia atropurpurea*
Sargassum muticum	*Falkenbergia rufolanosa*	*Phyllophora crispa*
Scytosiphon lomentaria	*Gastroclonium ovatum*	*Plocamium cartilagineum*
Stypocaulon scoparium	*Gelidium corneum*	*Polysiphonia spp.*
	Gelidium pusillum	*Pterosiphonia spp.*
	Gelidium spinosum	*Rhodothamniella floridula*
	Gigartina pistillata	*Scinaia furcellata*

The specific richness index ranged from 7 to 19 per site with an overall mean of 14.5 in the lower intertidal, and from 9 to 16 with an overall mean of 11.6 in the middle intertidal. On the other hand, the Shannon-Wiener diversity showed a similar pattern, ranging from 1.2 to 2.5 per site with an overall mean of 1.8 in the lower intertidal, and from 0.6 to 1.8 with an overall mean of 1.2 in the middle one. According to ANOVA analysis (Table 5.3), specific richness and Shannon-Wiener diversity did not show significant differences within geomorphological variables in the lower intertidal, except in the case of diversity related to the lithology variable. As seen in Figure 5.3, calcareous substrate presented higher diversity (1.9 mean value) than the siliceous (1.4 mean value), although the range of values was also broader in the first one. In the middle intertidal, both richness and diversity indices were significantly higher in areas without landslides (12.2 vs. 10.6 and 1.3 vs. 0.9, respectively). In this fringe, species richness was also significantly different between coastal orientations, presenting the highest number of species in the North orientation (13.8), the mean in the east (11.4) and the lowest one in the West (10.4).

Table 5.3. ANOVA test (*p*) on the richness (S) and diversity (H) indices according to geomorphological variables. Kruskal-Wallis (KW) test applied when a non-parametric test was required.

		Lower intertidal				Middle intertidal			
		df	MS	F	*p*	df	MS	F	*p*
Active processes	S	1	11.07	0.61	0.437	-	-	4.66 KW	0.031*
	H	1	0.03	0.09	0.765	-	-	7.46 KW	0.006**
Coastal morphology	S	1	45.99	2.59	0.111	1	35.21	3.88	0.052
	H	1	0.48	1.76	0.178	1	0.27	1.09	0.299
Coastal orientation	S	2	23.47	1.31	0.276	2	90.45	12.03	0.000**
	H	2	0.48	1.76	0.178	2	0.42	1.72	0.184
Lithology	S	-	-	3.83KW	0.051	1	19.14	2.07	0.154
	H	1	2.81	11.40	0.001**	1	0.31	1.27	0.263

* $p < 0.05$, ** $p < 0.01$

KW: Kruskal-Wallis test statistic

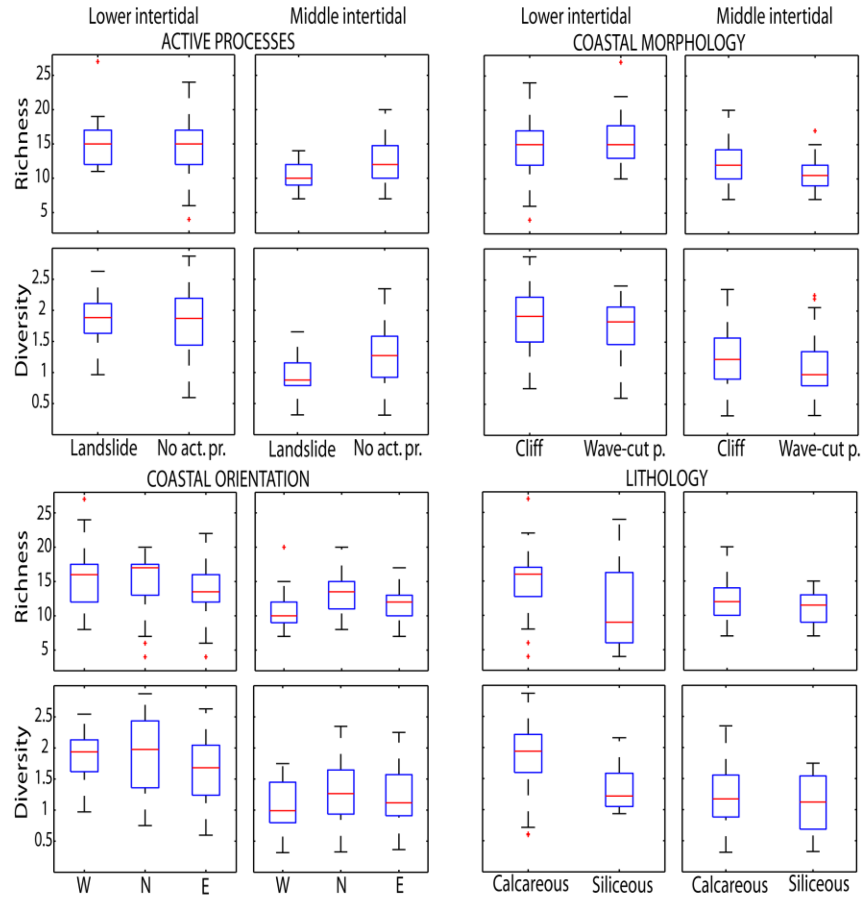


Figure 5.3. Box plots of species richness and Shannon Wiener diversity for each category of geomorphological variables. The middle line in the box is the median, the lower and upper box boundaries mark the first and third quartile. The whiskers are the largest and smallest observed values that are not statistical outliers (values more than 1.5 interquartile range), which are represented by a red cross. No act. Pr.: No active processes; Wave-cut p.: Wave-cut platform.

Regarding assemblage composition analysis, although differences within most of the geomorphological variables were statistically significant, R values were in general very low in the ANOSIM test (Table 5.4). For this reason, we considered species composition to be remarkably different when $p < 1\%$ and R > 0.2. This way, the structure of the macroalgae communities could be considered different according to coastal morphology in the lower intertidal and to coastal orientation in the middle intertidal.

Table 5.4. Results of global and pairwise test (R and *p*) from ANOSIM for differences among geomorphological variables.

Global test					
		Lower intertidal		Middle intertidal	
		R	*p* (%)	R	*p* (%)
Active processes		0.10	3.2*	0.00	46.1
Coastal morphology		0.24	0.1**	0.12	1.2*
Coastal orientation		0.17	0.1**	0.21	0.1**
Lithology		0.14	1.8*	-0.07	81.9

Pairwise test					
		Lower intertidal		Middle intertidal	
		R	*p* (%)	R	*p* (%)
Coastal orientation	E, W	0.11	0.3**	0.13	0.2**
	E, N	0.21	0.1**	0.19	0.1**
	W, N	0.17	0.1**	0.21	0.1**

* *p* (%) < 0.05, ** *p* (%) < 0.01

Finally, the response of individual species to geomorphological variables was examined. Before describing these results, it has to be noted that only two sites along the coast of Cantabria are of a siliceous nature. Thus, relations between lithology and specific species have to be analysed with caution, without generalising the effects of this particular factor. The species preselected by SIMPER analysis were those needed to reach a 90% cumulative contribution to dissimilarity between categories, which were 12 in the lower intertidal. From these, *Codium tomentosum, Cystoseira baccata, Gelidium corneum* and *Ulva* spp. showed no significant relation with geomorphological variables, according to the increment on deviance with respect to the null model (Table 5.5a). On the other hand, *Corallina officinalis/Ellisolandia elongata* was significant for all variables. As seen in Figure 5.4, this taxa has a great probability of occurrence in high slope and siliceous substrates that were North and West oriented and lacked active processes. On the contrary, *Bifurcaria bifurcata* appeared mostly in wave-cut platforms of a calcareous chemical nature that were West or East oriented. Related to the coastal morphology, *Ceramium* spp. and *Gelidium spinosum* showed a high presence in cliffs areas. Regarding coastal orientation, *Ceramium* spp., *Falkenbergia rufolanosa* and *G. spinosum* presented a great probability of occurrence in areas oriented towards the North, while *Caulacanthus ustulatus* mostly appeared in areas oriented towards the east. *Cystoseira tamariscifolia* and *Stypocaulon scoparium* showed opposite relationships to active processes, with *C. tamariscifolia* appearing at sites with landslides. In the case of *S.*

scoparium, however, probabilities have to be considered with caution because the maximum likelihood estimation did not converge even when the number of iterations increased. Finally, *G. spinosum* seemed to have a high probability of occurrence in siliceous substrates.

Table 5.5. Fitting diagnostics for different geomorphological variables in the lower (a) and middle (b) intertidal, including the rate of change on deviance (ΔDev) and the chi-square distribution assuming a confidence level α=95% (χ^2).

	ACTIVE PROCESSES		COASTAL MORPHOLOGY		COASTAL ORIENTATION		LITHOLOGY	
	Δdev	χ^2	Δdev	χ^2	Δdev	χ^2	Δdev	χ^2
a) LOWER INTERTIDAL								
B. bifurcata	0.36	7.81	44.89*	7.81	17.98*	12.59	20.02*	7.81
C. ustulatus	_	_	2.56	7.81	13.08*	12.59	_	_
Ceramium spp.	6.31	7.81	8.30*	7.81	16.16*	12.59	9.33*	7.81
C. tomentosum	1.45	7.81	2.17	7.81	9.99	12.59	6.55	7.81
C. officinalis/ E. elongata	18.19*	7.81	26.28*	7.81	27.97*	12.59	10.97*	7.81
C. baccata	_	_	_	_	9.09	12.59	_	_
C. tamariscifolia	11.47*	7.81	4.84	7.81	7.35	12.59	_	_
F. rufolanosa	6.49	7.81	_	_	20.65*	12.59	2.13	7.81
G. corneum	3.58	7.81	3.97	7.81	6.14	12.59	5.45	7.81
G. spinosum	5.35	7.81	8.54*	7.81	24.31*	12.59	16.58*	7.81
S. scoparium	9.57**	7.81	4.34	7.81	11.35	12.59	2.22	7.81
Ulva spp.	6.01	7.81	4.93	7.81	6.83	12.59	5.34	7.81
b) MIDDLE INTERTIDAL								
B. bifurcata	29,92*	21,03	_	_	15.13*	12.59	_	_
C. ustulatus	22,62*	21,03	0,43	7,81	9.61	12.59	12,24	7,81
Ceramium spp.	30,16*	21,03	2,54	7,81	10.34	12.59	4,09	7,81
C. acicularis	_	_	_	_	15.43*	12.59	_	_
Cladophora spp.	_	_	_	_	_	_	0,81	7,81
C. tomentosum	_	_	_	_	9.43	12.59	_	_
C. officinalis/ E. elongata	20,33	21,03	1,31	7,81	17.60*	12.59	3,33	7,81
C. baccata	_	_	_	_	2.24	12.59	_	_
C. tamariscifolia	_	_	_	_	4.40	12.59	_	_
F. rufolanosa	_	_	_	_	14.73*	12.59	_	_
G. corneum	_	_	_	_	2.17	12.59	_	_
G. spinosum	_	_	_	_	10.31	12.59	_	_
L. incrustans	54,7**	21,03	19,9*	7,81	_	_	7,67	7,81
O. pinnatifida	16,08*	21,03	1,51	7,81	_	_	_	_
S. scoparium	17,73	21,03	6,82*	7,81	7.35	12.59	1,45	7,81
Ulva spp.	27,67**	21,03	9,73*	7,81	3.31	12.59	8,29	7,81

* ΔDev> χ2

** ΔDev> χ2 but maximum likelihood estimation did not converge

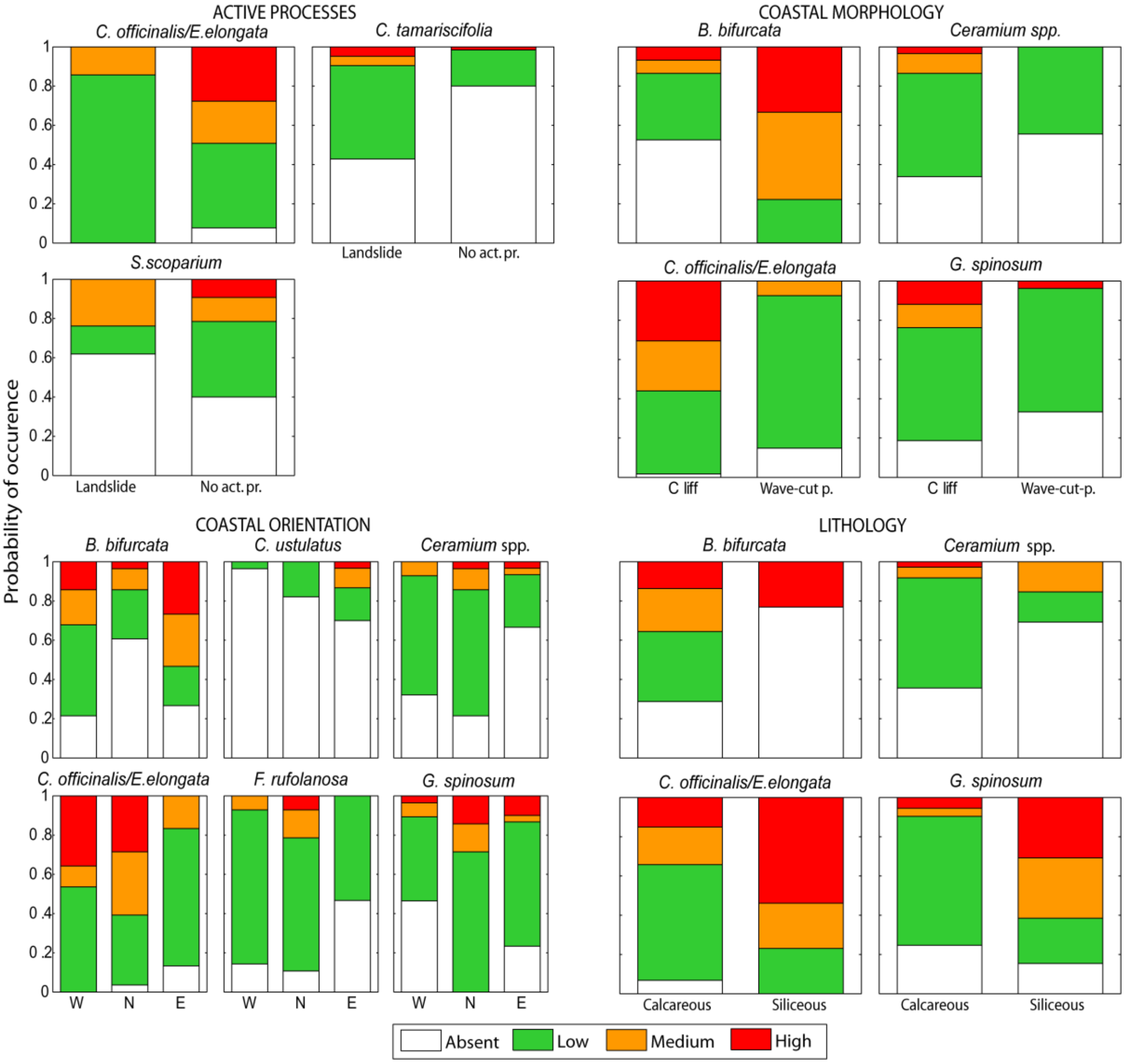


Figure 5.4. Probability of occurrence of each species conditioned to geomorphological variables (active processes, coastal morphology, coastal orientation and lithology) in the lower intertidal. No act. Pr.: No active processes; Wave-cut p.: Wave-cut platform.

In the middle intertidal, 17 species were preselected by SIMPER analysis. Six species, *Cladophora spp, C. tomentosum, C. baccata, C. tamariscifolia, G. corneum* and *G. spinosum,* were not significantly related to geomorphological variables according to the logistic model (Table 5.5b). On the contrary, *Ulva* spp. was entered into the model for its significant relationship to active processes and coastal morphology, although Figure 5.5 showed the broad tolerance of this cosmopolitan taxa for both variables. Several taxa exhibited a higher probability of occurrence where there are no landslides processes, such as *B. bifurcata*, *C. ustulatus*, *Ceramium* spp., *Litophyllum incrustans* and *Osmundea pinnatifida*. *L. incrustans* showed a slightly higher probability of occurrence in cliffs substrates. For *Chondracanthus acicularis* and *F. rufolanosa,* an increase in presence probability was observed in coasts oriented towards the North, whereas *C. officinalis/E. elongata* presented a high probability of occurrence along all orientations. Lithology variables did not present any significant relationship with species at this level.

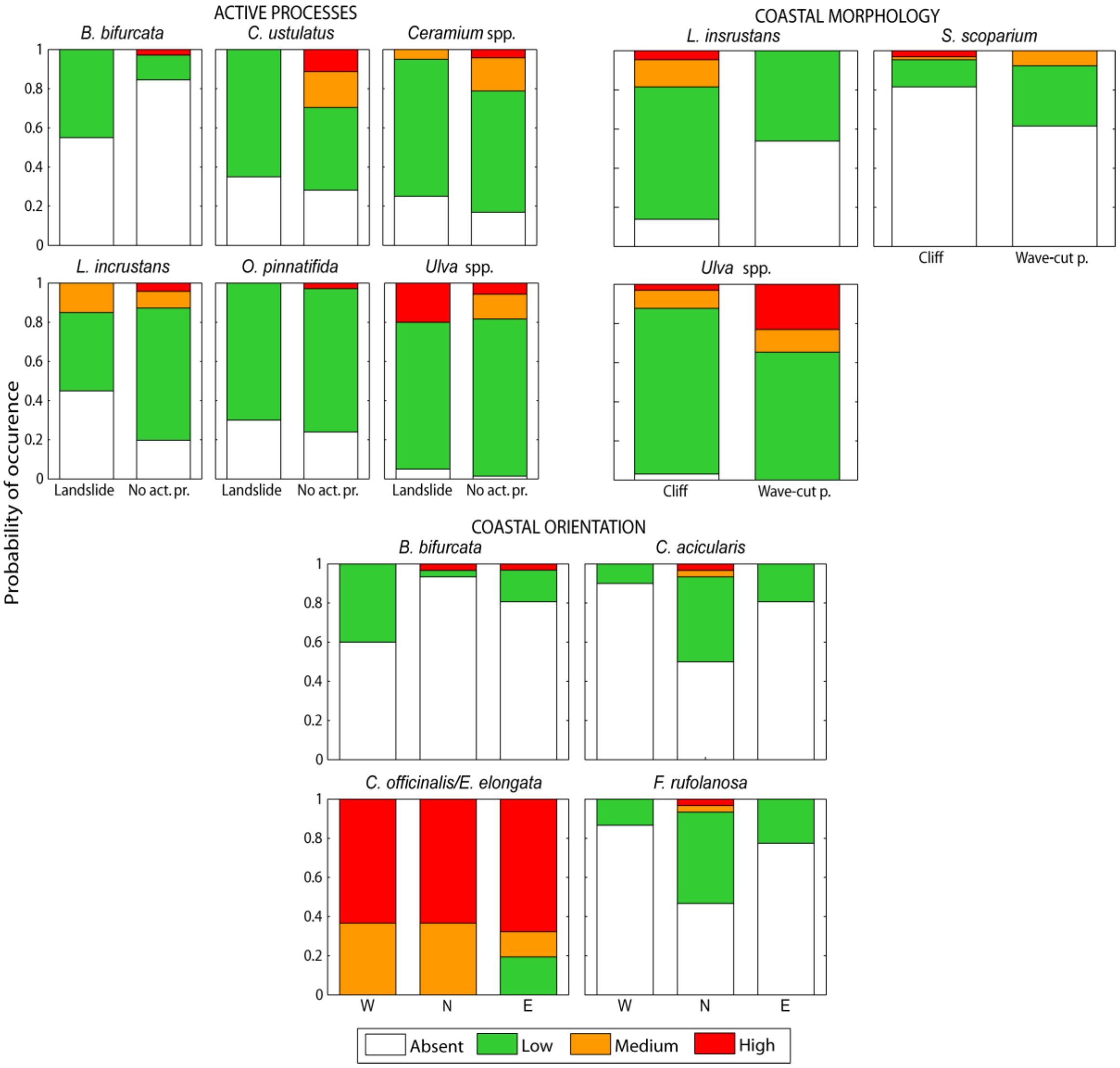


Figure 5.5. Probability of occurrence of each species conditioned to geomorphological variables (active processes, coastal morphology and coastal orientation) in the middle intertidal. No act. Pr.: No active processes; Wave-cut p.: Wave-cut platform.

5.4. Discussion

According to the results obtained, intertidal macroalgae distribution is partially related to geomorphological features at a local scale. This influence happens in different ways and with different intensities depending on the intertidal zone and the level of organisation analysed. In relation to species richness and diversity, slight differences were detected between most of the geomorphological factors. The assemblage composition seems to be partially determined by coastal morphology and coastal orientation, and several species (i.e., *Bifurcaria bifurcata, Corallina officinalis/Ellisolandia elongata, Falkenbergia rufolanosa, Gelidium spinosum*) showed preferences according to geomorphological characteristics.

This work provides an advanced and appropriate approach in the study of geomorphological features and seaweed distribution to improve knowledge about their relationship. The observational and descriptive method here applied seems to be highly relevant, as studies using artificial surfaces may be extremely misleading (McGuinness, 1989). In addition, quantifying the associations between the probability of occurrence of marine species and abiotic environmental variables by logistic regression may generate robust predictions of distribution, even if the mechanisms or processes that explain the effect of the type of substratum on the abundance of sessile species in marine habitats are not known (Ysebaert et al., 2002; Ellis et al., 2006). According to McGuinness (1989), the reasons for these effects are not clear, but may include differential grazing by invertebrates or differential retention of spores, water or heat.

In general, species richness and Shannon-Wiener diversity indexes did not show strong patterns related with geomorphological features. Active processes in the middle intertidal were the only variable significantly related to both richness and diversity indexes, as these indexes were higher in areas without landslides. The explanation for this could be that disturbance, caused by active processes in this case, results in reduced diversity by causing mortality and recruitment inhibition of less tolerant species and/or enhancing the spatial dominance of a few tolerant space-monopolising species (Schiel et al., 2006).

The variables that show significant differences according to the composition and structure of the communities, coastal orientation and coastal morphology, seem to be associated with other factors that ultimately determine species distribution. Coastal orientation is related to the exposure to wave action of a particular area. This geomorphological factor is especially related to assemblage composition in the middle intertidal, which can also be related with exposure because the smashing and tearing effects of waves reach a zenith in this zone (Nybakken, 1997). A similar work carried out by Wallenstein and Neto (2006) in the Azores Island showed that wave exposure is more important at the mid-littoral level, as was observed here with coastal orientation. On the other hand, coastal morphology is related to the slope of the substrate. Slope indirectly affects macroalgae distribution by affecting the types of flows and sediment deposition (Díez et al., 2003). Both slope and exposure have been mainly studied because of their relationship with intertidal macroalgae (e.g., Sousa, 1984; Lüning, 1990; Wallenstein and Neto, 2006; Rinne et al., 2011; Spatharis et al., 2011; Troncoso and Sibaja-Cordero, 2011).

In spite of our expectations, active processes that affect richness and diversity do not present differences in the assemblage composition. This may be explained by the particular species that vary, as most are rare species with a low cover (e.g., *Apoglossum ruscifolium, Gymnogongrus crenulatus, Heterosiphonia plumosa, Nitophyllum punctatum, Polysiphonia* spp. and *Pterosiphonia* spp.). As such, the absence of this species in places with landslides causes the decrease in specific richness and Shannon-Wiener diversity indexes, even though it does not modify the general structure of the communities, as the keystone species and those with a higher cover remain similar.

Regarding specific species, *C. officinalis/E. elongata* showed a higher probability of occurrence in coasts orientated towards the West and North. This preference may be related to the elevated exposure to wave action of these orientations, as *C. officinalis/E. elongata* is an articulated calcareous taxa theoretically adapted to cope with exposed conditions and usually much more abundant in open coasts (Fernández and Niell, 1982; Puente and Juanes, 2008; Spatharis et al., 2011). This difference is especially marked in the lower intertidal, because in the middle intertidal *C. officinalis/E. elongata* is so abundant that it shows a high cover along the entire coast. On the other hand, *C. officinalis/E. elongata* and *G. spinosum* showed higher probabilities of occurrence in cliffs than in wave-cut platforms, in accordance with observations related to the slope of the substrate in the nearby coast of Asturias (Fernández y Niell, 1982). There are other species, such as *Ulva* spp, which show a cosmopolitan character, appearing throughout the study area without any preference for specific substrates.

As previously mentioned, *C. officinalis/E. elongata* is the clear dominant taxa in the middle intertidal, while in the lower intertidal there seem to be two opposite communities, one dominated by *B. bifurcata* and another by *C. officinalis/E. elongata* and *G. spinosum* (Puente, 2000; Araújo et al., 2005). The first community appears in wave-cut platforms, oriented towards the east and of a calcareous chemical nature, while the second one appears in siliceous cliffs oriented towards the North and West. The relation between lithology and specific species could be inaccurate as only two sites along the coast of Cantabria are of a siliceous nature. This is the case of *G. spinosum*, which shows a preference for siliceous substrates, while, conversely, increase from the West (mostly siliceous shore) to the east (mostly calcareous shore) along the Iberian Peninsula (Anadón, 1983; Gorostiaga et al., 2004). On the other hand, the possible effect of calcareous encrusting macroalgae (e.g., *Lithophyllum incrustans, Mesophyllum lichenoides*) has to be taken into account. These species may create a biological substrate of a calcareous nature where epiphytic species are able to grow.

It appears that although geomorphological variables help to characterise species distribution, their predictive value is still limited. This could be explained by the influence of other variables on setting distribution patterns, such as biological interactions, which are of great importance at this local scale and also vary depending on the intertidal level. In the middle intertidal, the physical environment and grazing cause changes in algal composition, while in the lower intertidal, competition for space and light by the various algae are the dominant interactions that structure communities (Nybakken, 1997). In addition, the interactive effects of different factors on the structure of communities are important. Caution is needed when generalising about the effects of one variable alone; for example, orientation and surface composition may interact with each other and/or with other factors, influencing the composition of epibiota communities (Glasby, 2000). Thus, future efforts should be made at a larger scale in order to detect both the individual and the interactive effects of all biological and physical factors, including geomorphological ones, in species pattern distributions.

In conclusion, the geomorphological variables studied show a relation with intertidal macroalgae patterns at a local scale. However, these variables do not seem to be the most determining agents because in most cases they are related to other factors that ultimately define the distribution of species in the different levels of the intertidal. Regarding descriptive parameters, specific richness is related to the orientation of the coast, and this index together with diversity is related to active processes in the middle intertidal. The structure assemblage varies according to coastal morphology in the lower intertidal and to coastal orientation in the middle level. Finally, several species show substrate preferences, such as *B. bifurcata* that appears in wave-cut platforms oriented towards the east, or *C. officinalis/E. elongata* and *G. spinosum*, which are found in cliffs oriented towards the North and West. In any case, the knowledge obtained here about the relationships of species with environmental factors will be helpful for decision-making on the management and conservation of natural resources, offering a means to predict the composition and structure of sustainable systems over space and time (Richardson and Berish, 2003).

Chapter VI

Coastal classification at local scale

Chapter VI. Coastal classification at local scale

Abstract

An ecological classification at a local scale may be a useful tool for conservation planning and for the implementation of effective programs and specific management in a particular region. For this purpose, the methodology previously applied at lower scales has been adapted to classify the coast of Cantabria (N Spain). This methodology includes two consecutive steps, a physical classification and a biological validation. Firstly, the shore line has been divided in 1 km stretches and indicators of the abiotic variables sea surface temperature, photosynthetically active radiation, significant wave height and coastal morphology have been calculated for each one. A hierarchical classification was proposed, a first level that encompasses quantitative variables grouping based on SOM and k-mean analysis and a second level that subdivides the previous groups according to the categorical variable coastal morphology. To validate the classification with biological data, covers of intertidal macroalgae species were homogenously obtained in 14 sites along the study area and several statistical analyses were applied to test its ecological significance. Thereby, three groups or physical units based on abiotic variables were obtained (W, C and E coast), each one subdivided in subunits according to their coastal morphology (cliffs or wave-cut platforms). A general agreement between macroalgae distribution and physical units was accomplished. In the lower intertidal, *Bifurcaria bifurcata* and *Stypocaulon scoparium* dominated the western and centre areas, while *Corallina officinalis/Ellisolandia elongata* and *Gelidium* spp. were most abundant towards the east. On the other hand, throughout the middle intertidal *C. officinalis/E. elongata* was the dominant taxa. The classification developed in this work complete a hierarchical framework to classify the NE Atlantic coast, a promising standard approach that allows to apply the most suitable resolution according to the study extension and that could be applicable to a wide range of coastal areas.

6.1. Introduction

An integrated management of the coast require the characterisation of marine assemblages and species distribution in order to preserve and maintain the integrity and services of ecosystems through the conservation of marine diversity (Douvere, 2008; Douvere and Ehler, 2009). Ecological classification arises as a useful tool that facilitates the quantification of the responses of biological patterns and processes to human uses at a certain region. It may also be useful for the development of conservation strategies to preserve species in degraded or fragmented areas, as well as in shifting habitats due to climate change (Rice et al., 2011). Classifications have been developed and used at several scales, ranging from broad biogeographic provinces to fine-scale divisions. The availability of classifications at different scales represents an essential element for an appropriate management and protection of coastal areas (Bianchi et al., 2012), since it allows to develop action plans at scales that are both ecologically meaningful and appropriate to the integrated management needs. This feature is particularly important for many policies and management initiatives which also have a range of scales, with goals set at national o regional domains but implemented at more local scales (Rice et al., 2011).

This work is focused on local scale, a decisive level in coastal management approaches (Stojanovic et al., 2010; Sale et al., 2014). Local areas need to be addressed on a case by case basis, since each zone is unique in terms of locally specific environmental, social and economic characteristics (Reis, 2014). Additionally, in terms of climate change, many adaption and mitigation actions must take place at reduced scales and are quite site-specific due to the different vulnerabilities of local communities and ecosystems (McCarthy et al., 2001). Thus, classifications at a local scale may be useful for conservation planning and for the implementation of effective biomonitoring programs in a particular region (Hawkins et al., 2000). In particular, along the NE Atlantic coast previous classifications have been carried out at a European (Ramos et al., 2012; Ramos et al., 2014) and regional scale (Ramos et al., in press), a further approach with higher resolution would be very useful in order to cover the complete range of scales.

The general premise in the last decade studies about classification systems is that biological communities respond to physiographic variables used to delineate ecological units (Gregr et al., 2012; Ramos et al., 2014; Ramos et al., in press). At a local scale, other factors aside from climatologic and oceanographic ones are important in the distribution of macroalgae, as geomorphological features (McGuinness and Underwood, 1986; McGuinness, 1989; Bird, 2008; Ramos et al., submitted) and the height along the intertidal zone (Wallenstein and Neto, 2006; Ramos et al., in press). Therefore, in a classification developed in a reduced area these factors should also be considered.

Regarding macroalgae communities, the North coast of the Iberian Peninsula presents some unique biogeographical characteristics, with a marked longitudinal gradient. The transitional character of this area (Ramos et al., in press) is also relevant to the study of the responses of intertidal communities to gradual variations in environmental conditions as that caused by climate change, on view of the evidence that the boundaries of some species have moved east- and westwards during the last century (c.f. Arrontes, 2002; Fernández, 2011). Taking into account this particular characteristic, this area seems to be appropriate to develop a local scale classification, being enclosed in the same biotype (A2) at a European scale (Ramos et al., 2012; Ramos et al., 2014) and in the same typology (E Cantabric) at a regional level (Ramos et al., in press).

The aim of this paper is therefore to establish a methodology to classify coastal waters at a local scale based on physical variables and verify its suitability regarding the actual distribution of intertidal macroalgae communities. The methodology follows the approaches previously developed at a European (Ramos et al., 2012; Ramos et al., 2014) and regional (Ramos et al., in press) scales. Thus, the higher level of resolution approach will complete a hierarchical classification system from large to small areas along the NE Atlantic coast, a useful approach for management and preservation of coastal ecosystems.

6.2. Methodology

6.2.1. Study area

This study was carried out in the coast of Cantabria, approximately 200 km long, located in the North of the Iberian Peninsula (NE Atlantic). The coastline is dominated by rocky substrata, with cliffs and wave-cut platforms, intercalated by sandy beaches (Ramos et al., submitted). This coast is in general very exposed, because of its orientation towards N and NW (the direction of the dominant winds), its own physiography and the prevailing hydrodynamic regime. The tides are semi diurnal with a mean tidal range of 3 m and a spring tidal range of 5 m.

Macroalgae distribution in the intertidal area of the Cantabric coast is mainly determined by the tidal height, where two clear fringes can be distinguished (Fernández and Niell, 1982; Anadón, 1983; Guinda et al., 2008; Ramos et al., in press): the middle intertidal, dominated by *Corallina officinalis/Ellisolandia elongata* and accompanied by calcareous encrusters, *Caulacanthus ustulatus*, *Ceramium* spp., *Chondracanthus* spp., *Osmundea* spp., etc., and the lower intertidal, dominated by *Bifurcaria bifurcata* and accompanied by *Stypocaulon scoparium, Codium* spp., *Cladostephus* spp., Champiaceae, *Gelidium* spp., etc.

To apply a uniform procedure for the preliminary division of the entire study area, sections of 1 km length were established by cutting a smooth digital coastline, without estuaries, using ArcGis (ESRI). 209 stretches were obtained. The length of the coastal stretches recognizes the variability of environmental conditions at a local scale and properly characterised the study area, thus, this length was considered the optimum (Figure 6.1).

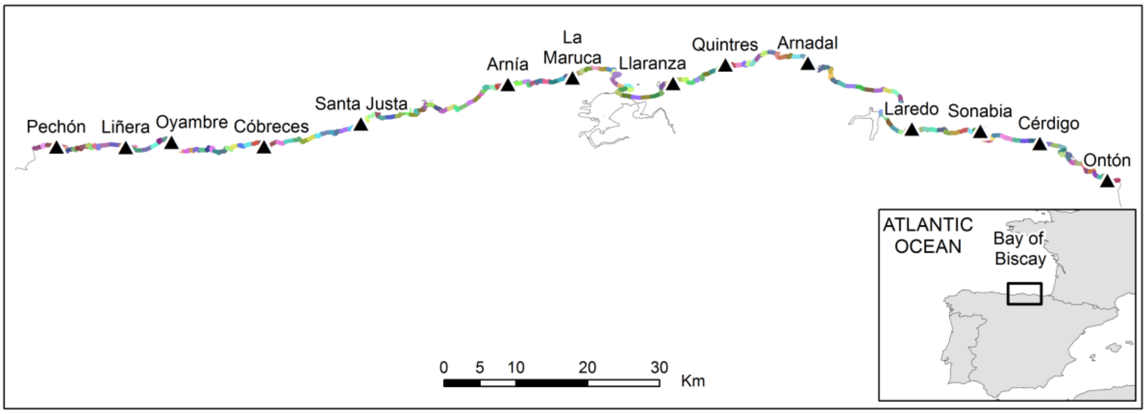


Figure 6.1. Location of the study area. Preliminary division of the coast of Cantabria into 1 m stretches. Location of biological data sampled sites represented by triangles.

6.2.2. Physical classification

6.2.2.1. Collection of physical data

The selection of abiotic variables was based on the criteria established by Ramos et al. (2012): (1) significant spatial variability at local scale along the study area, (2) proposed in other classifications at similar scale (Wieland, 1993; Verfaillie et al., 2009; Briceño et al., 2013; Allee et al., 2014; Richmond and Stevens, 2014), (3) related to the geographical distribution of macroalgae communities, (4) possibility of obtaining quantitative and homogenous data at the necessary scale within the study area and (5) not mutual influence (intercorrelation coefficient lower than 0.95) between indicators of the variables. Thus, the physical indicators employed in Ramos et al. (2012) (sea surface temperature (SST), photosynthetically active radiation (PAR), wave height, tidal range and salinity) were adapted to the local scale of this study. At this level of resolution, minimum changes in sea surface temperature could determine the presence or absence of certain species, especially the extremely high temperatures that seem to be the cause of the distribution shifts in species along the north of the Iberian Peninsula (Voerman et al., 2013). Therefore, another indicator of temperature was included, the annual 99th percentile. Tidal range and minimum PAR were not considered because they do not vary significantly along the study area. Finally, coastal morphology was added, because of its influence on macrophytes at this local scale (Ramos et al., submitted). This way, the physical variables selected were SST (average, minimum and 99th percentile (P99)), PAR (average and maximum), significant wave height and coastal morphology (cliff, wave-cut platform or beach).

Specific procedures were applied for obtaining each variable because of its different nature (Table 6.1). Temperature and radiation were estimated by satellite sensors. Data from the Group for high Resolution Sea Surface Temperature (GHRSST) L4 products were used for SST and from MyOcean (MODIS-Aqua and SeaWIFS sensors) products for PAR. These data series were obtained from the nearest point with satellite information to reference points situated 2 km away from the coast, in the centre of each stretch. The wave height was calculated along the depth of closure, considered appropriate to characterise the intertidal area (Tomas et al., 2013), based on downscale wave reanalysis (DOW, Camus et al., 2013). Finally, coastal morphology was obtained by the analysis of Geologic Maps of Spain (Geological and Mining Institute of Spain, IGME) and by field work in some cases (Ramos et al., submitted).

Table 6.1. Data sources and methodologies for the quantification of each environmental variable (see text for the full name of acronyms).

Variables	Source	Data series		
		Period	Temporal resolution	Spatial resolution
SST	GHRSST (sensors)	2005-2008	Daily average	0.02°
PAR	MyOcean (SeaWifs and Modis Aqua sensors)	1997-2010	Monthly average	2 km
Wave height	Reanalysis DOW	1948-2008	Monthly average	200 m
Coastal morphology	Geologic map (IGME) and field work	-	-	1 km

6.2.2.2. Classification procedure

A two-steps hierarchical classification was carried out. The first level encompasses a statistical classification that includes the quantitative variables. This way, coastal stretches were grouped according to physical data series combining two techniques: Self-Organizing Maps (SOM) (Kohonen, 2001), a technique included in neural networks (Artificial Neural Networks, ANNs), and the K-means algorithm (Hastie et al., 2001) (c.f. Camus et al., 2011; Ramos et al., in press). Map size determination is one of the key points in SOM application. In this study, the optimum map size (number of units) was chosen based on the heuristic formula proposed by Vesanto et al. (2000), $M = 5\sqrt{N}$ where M is the number of map units and N is the number of samples of the training data. In addition, it was corroborated that the number of units chosen was an optimum solution based on the minimum values for quantization and topographic errors by trained with different map sizes. Previously to the SOM training, variables were normalized at an interval of [0, 1] by linear transformation for each variable in each stretch. SOM and k-means analyses were conduct using Matlab 7.7 and the SOM coding solution based on SOM Toolbox for Matlab 5 (Vesanto et al., 2000).

Finally, the second level of the classification was accomplished. The units previously obtained were subdivided by adding the categorical variable coastal morphology. This way, statistical units were segregated between cliffs and wave-cut platforms (subunits).

6.2.3. Biological validation and characterisation

6.2.3.1. Collection of macroalgae data

In order to obtain biological data, a homogenous and standardized sampling methodology was carried out during spring tides in April 2011 and May and June 2012. 14 sites were surveyed along the coast of Cantabria (Figure 6.1), as specified in Ramos et al. (submitted). In every site three transects perpendicular to the coast were established. Inside each transect a stratified sampling was carried out by the distribution of three sample stations (quadrats) of 50 x 50 cm in the lower and in the middle intertidal (Figure 6.2). According to Ramos et al. (in press), these are the intertidal levels where seaweeds are a structural element and, thus, where a biological validation should be carried out. This way, a total of 177 quadrats were recorded. Cover of macroalgae species were obtained by photo analyses as described in Ramos et al. (in press), since this methodology works appropriate in similar approaches.

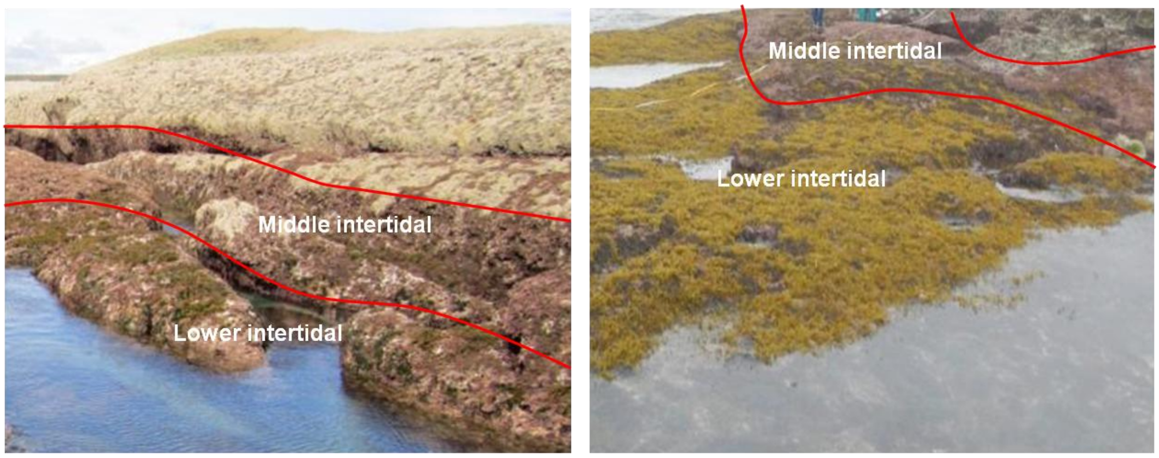


Figure 6.2. Vertical zonation along the study area where lower and middle intertidal fringes can be distinguished (Llaranza and La Maruca sites).

Additionally, the height of each point of interest (i.e., quadrats, start and end of transects, limit between intertidal levels) has been calculated. For this purpose, horizontal and diagonal distances from one point of interest to another were obtained using a measuring tape and a distance laser respectively. Then, relative heights were estimated by Pythagoras function. The lowest sea level was calculated based on astronomic tides.

6.2.3.2. Biological validation and characterisation procedure

Firstly, distribution maps were generated to analyze macroalgae species patterns in both vertical and longitudinal gradients, based on a data matrix with average cover of the most abundant species per height (quadrat) and site. Graphic schemes of interpolated cover values were used, representing the spatial distribution of sites along the coast at the X axis (based on UTM coordinates) and the height above the sea level gradient at the Y axis. The interpolation to create the coverage of isolines was done using the “Kriging” method. These maps are a proxy of cartography, a model of the distribution of the macroalgae species in height along the intertidal. Surfer 8.0 was the software used for this task.

Then, several statistical analyses were carried out to test and validate the adjustment between macroalgae distribution and physical units (obtained by SOM and k-means analysis) and to examine the improvement of the physical classification by the addition of the variable coastal morphology (subunits). A MDS analysis was carried out to identify patterns and gradients in the macroalgae communities, based on a Bray-Curtis similarity matrix with fourth root transformed cover data per quadrat. Then, a two-way ANOSIM test was applied to detect differences in the species composition among units and different categories of coastal morphology. These statistical analyses were performed with the package PRIMER-E (v.6 + PERMANOVA) (Clarke and Gorley, 2006).

In addition, we evaluate similarities between physical and biological variables using component planes (Vesanto, 1999). This analysis consists on the graphical representation of the physical variables previously included in the SOM and the macroalgae data. Only the 20 species with the highest average cover per site in each intertidal level were represented. The simultaneous inspection of multiple component planes allows for the visualization of correlated variables, since closed placed planes are indication for similar behaviour or correlation between respective variables. This analysis was carried out using Matlab 7.7 and the SOM Toolbox 2.0 (Vesanto et al., 2000).

6.3. Results

6.3.1. Physical classification

The geographic distribution of physical variables can be observed in Figure 6.3. Values of each variable were represented by three equal interval classes. Average and P99 sea surface temperature presented similar general patterns, progressively increasing eastwards. However, the minimum SST and average and maximum PAR followed a different trend, being minimum at both border areas. On the other hand, average and minimum SST showed a very narrow range, with P99 SST presenting a slightly higher range of around 1 °C. Regarding radiation indicators, also the maximum exhibited a higher variability than the average. The exposure to wave action presented the highest range, with significant wave heights between 0.2 and 2 m. This variable showed also a more patched pattern, although, in general, the lowest values can be observed towards the East. At the same time, areas closed to estuaries experienced minimum wave conditions due to their protected nature. Finally, the coastal morphology along the coast of Cantabria is mostly cliffs, interspersed with limited wave-cut platforms and beaches, mostly around estuaries.

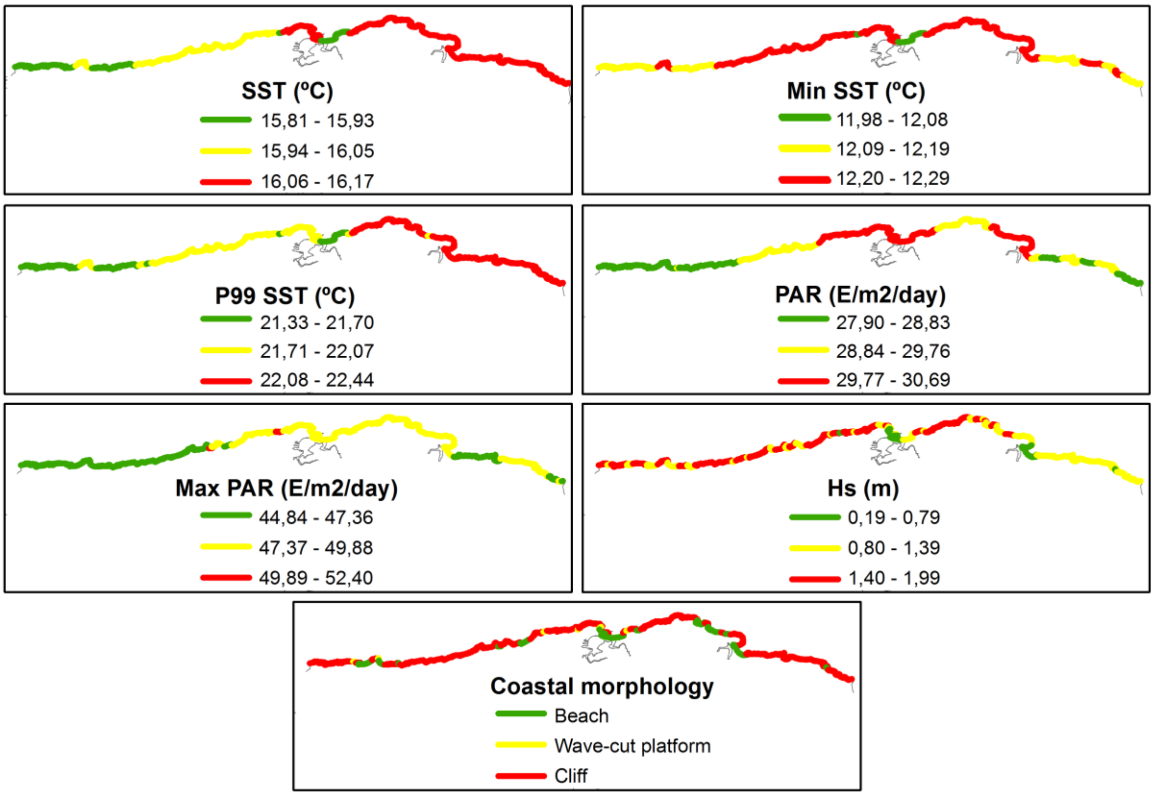


Figure 6.3. Spatial distribution of physical variables along the coast of Cantabria. Visualization of data using a three interval classes. From top left: average SST, minimum SST, P99 SST, average PAR, maximum PAR, average wave height and coastal morphology.

As the first level of the physical classification, the six quantitative indicators were included in the SOM training. Based on the heuristic formula previously explained, the map size selected was 72 units (9 x 8 neurons). The trained map had minimum quantization and topographic errors, 0.13 and 0.02 respectively. This map preserved well the topology of the input data (Kohonen, 2001), and was relevant for subsequent interpretations.

As can be seen in the results shown in Figure 6.4a, SOM technique made a clustering of the data set that makes it possible to observe very intuitively how the stretches are grouped according to their characteristics. However, for a more manageable and simplified classification, the k-means technique was applied to the groups obtained in the SOM. Taking into account the reduce study area, three k-means clusters were considered an adequate number of groups that seems to represent well the natural environmental variability of the coast. Figure 6.4a shows the limits of the groups obtained with this technique. Clusters were also presented on a geographical map of the study area, in order to ease interpretations (Figure 6.4b).

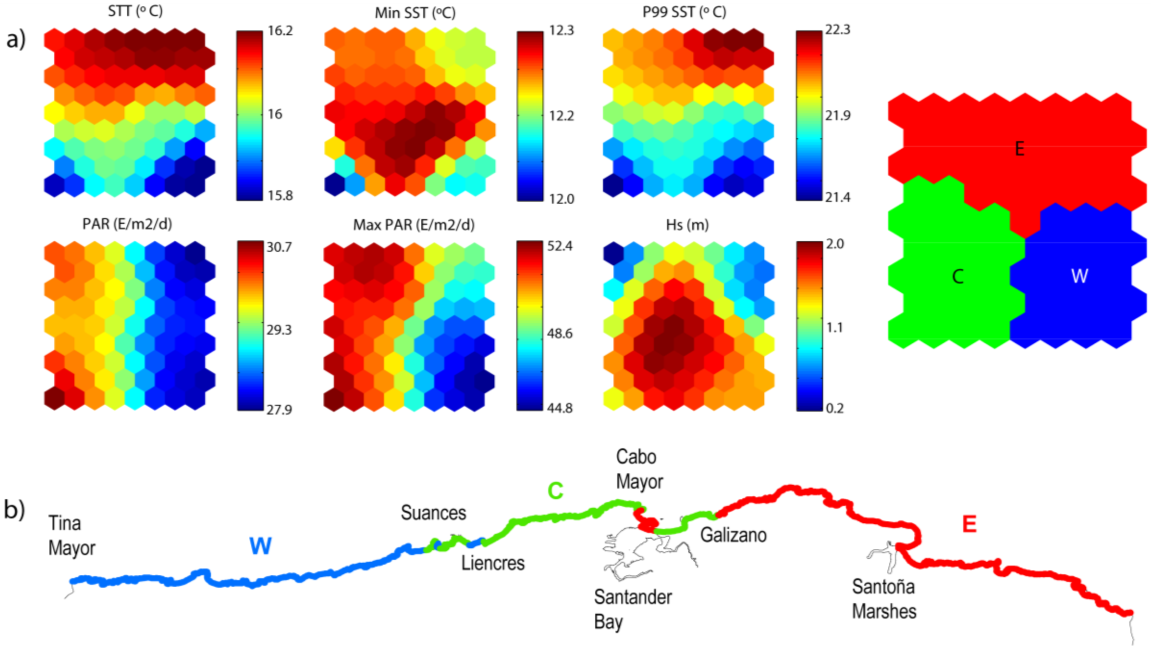


Figure 6.4. (a) Left, Gradient analysis of each physical variable on the trained SOM. Right, K-means results on the SOM plane. (b) Geographical projections of the units obtained in physical classification (based on SOM and k-means statistical analyses results).

The mean and standard deviation values of each unit (k-means groups) are summarized in Table 6.2. As can be seen, some variables presented average values a bit similar between units due to the small study area. This is specially marked in the case of minimum SST variable, which average is 12.2 °C in all the groups. The main characteristics of the three units obtained are:

- W (Western coast): it included the area from the border with Asturias (Tina Mayor) to the zone between Suances and Liencres. It was characterized by the lowest sea surface temperature and maximum radiation.

- C (Centre coast): it was established from Liencres to the Bay of Santander area, showing an intercalated section with the next unit (E) from Cabo Mayor until

Galizano. This unit presented the maximum values of wave height and low average and P99 SST.

- E (Eastern coast): it comprised the eastern part of Cantabria, from the Bay of Santander, where, as said before, a section is intercalated with C unit, to the border with Basque Country (Cobaron). This area was characterized by the lowest wave height and the higher average and P99 temperature.

Table 6.2. Average and standard deviation values for each physical variable in each unit.

Unit	SST (°C)	Min SST (°C)	P99 SST (°C)	PAR ($E/m^2/d$)	Max PAR ($E/m^2/d$)	Hs (m)
W	15.89 ± 0.08	12.20 ± 0.07	21.64 ± 0.15	28.79 ± 0.20	45.83 ± 0.49	1.45 ± 0.21
C	15.97 ± 0.09	12.22 ± 0.10	21.77 ± 0.21	29.99 ± 0.34	48.69 ± 0.86	1.53 ± 0.32
E	16.13 ± 0.03	12.21 ± 0.03	22.19 ± 0.13	29.36 ± 0.64	48.24 ± 1.02	1.14 ± 0.37

As the second level of the physical classification, a hierarchical scheme was carried out, by adding the variable 'Coastal morphology' to the statistical classification. This way, units W and C were subdivided into W-cliffs, W-wave-cut platforms, C-cliffs and C-wave-cut platforms, while unit E remained the same since there are not wave-cut platforms in this area.

6.3.2. Biological validation and characterisation

A total of 65 different macroalgae taxa were identified, 62 in the lower intertidal and 55 in the middle one (taxa list in Table 5.2, Chapter V). Among these, the most abundant taxa were *Corallina officinalis/Ellisolandia elongata*, *Bifurcaria bifurcata, Gelidium spinosum*, and *Stypocaulon scoparium*. The species richness ranged from 21 to 40 per site, in Sonabia and Liñera respectively, with an overall mean of 35. Besides, the Shannon-Wiener diversity ranged from 1.9 to 2.9 per site, in Quintres and Cóbreces respectively, with an average value of 2.7.

A proxy of cartography of the most important macroalgae species are shown in Figure 6.5. These graphic schemes represent the location of the sites using coordinates (X axis) and height above sea level from 0 to 1.4 m (the middle intertidal average height obtained in Cantabria) (Y axis). According to average height values, the limit between the lower intertidal and middle intertidal was found around 0.6 m in this coast. As shown in the abundance distribution maps, *C. officinalis/E. elongata* and *B. bifurcata* were the dominant taxa in the middle and lower intertidal of Cantabria, respectively, due to their extensive distribution and high cover. *C. officinalis/E. elongata* remained more or less constant for the entire longitudinal gradient, while *B. bifurcata* was more abundant in the W and C units. In the lower intertidal there was a high cover of *G. spinosum* in the eastern area, and of *S. scoparium* in the western and centre areas. Finally, the remainder macroalgae species showed distribution patterns related with height, with different preferences for the middle (*Caulacanthus ustulatus)* or the lower intertidal (*Codium tomentosum). C. ustulatus* showed as well higher cover towards the East.

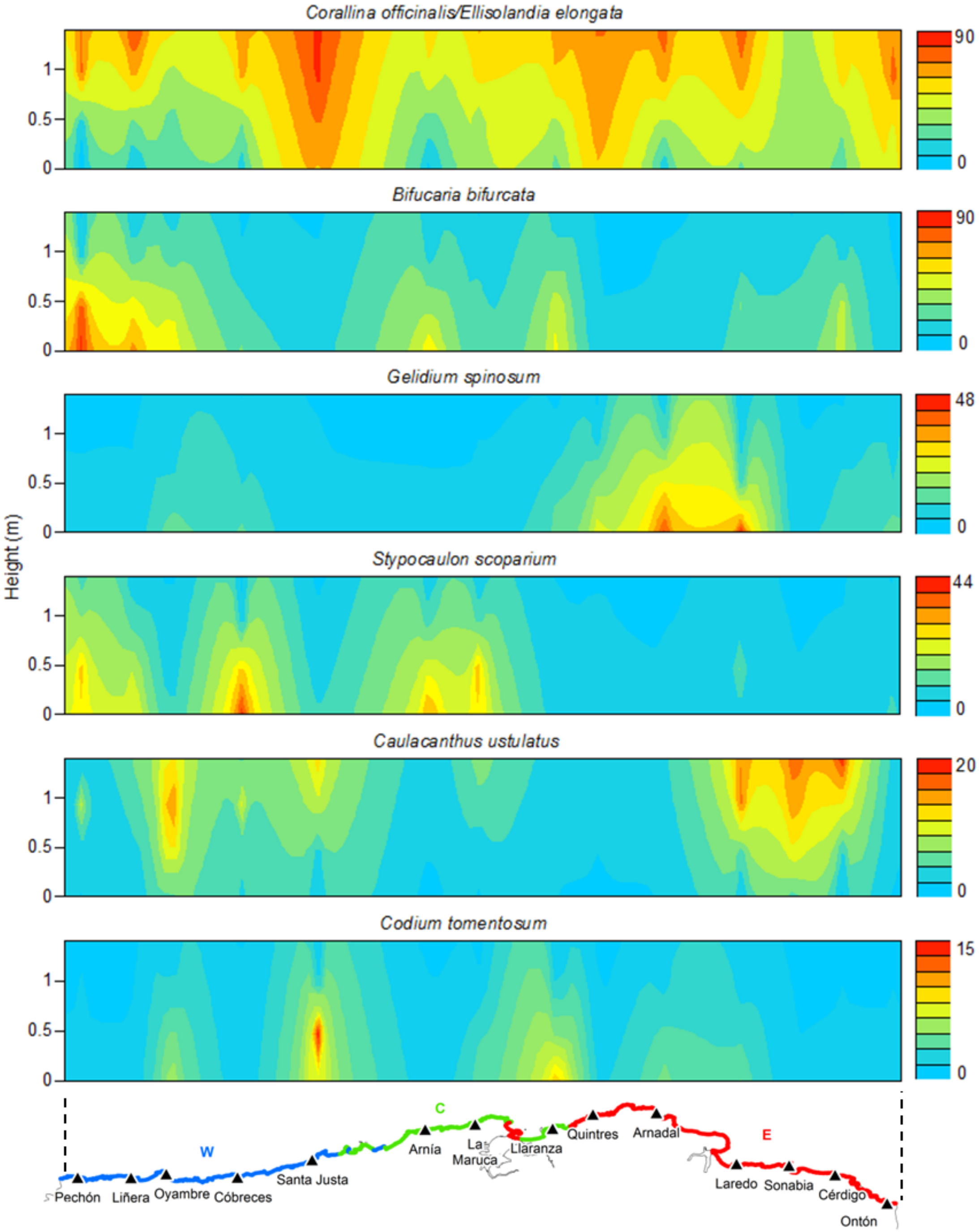


Figure 6.5. Interpolated graphic representations of *Corallina officinalis/Ellisolandia elongata*, *Bifurcaria bifurcata, Gelidium spinosum, Stypocaulon scoparium, Caulacanthus ustulatus* and *Codium tomentosum* distributions.

The ordination analysis ratified the general agreement between macroalgae distribution and physical units, though there were noticeable differences between intertidal levels. As can be observed in Figure 6.6a, in the lower intertidal quadrats from the unit E were differentiated in the right part of the graph, the ones from the unit W were in the left and, finally, the unit C quadrats were situated between them. In the middle intertidal, units C and E could also be differentiated, while quadrats of the unit W were more dispersed. Fig. 6.6b shows the pattern of coastal morphology variable within the two units that presented cliffs and wave-cut platforms (W and C). In both intertidal levels the centre group showed a clear difference between cliffs, located on the upper part of the MDS graph, and wave-cut platform, located on the bottom. Regarding the unit W, in the lower intertidal this pattern could still be distinguished, while in the middle intertidal cliffs and wave-cut platform quadrats were distributed throughout the graph.

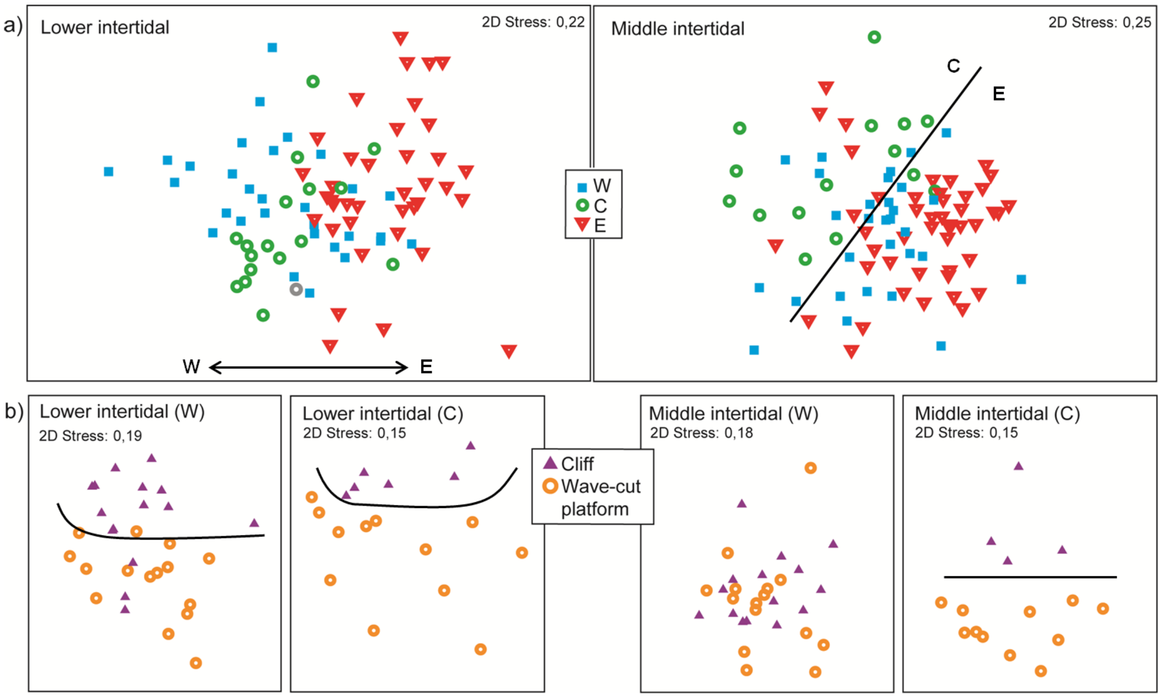


Figure 6.6. MDS analysis based on macroalgae distribution. (a) Quadrats are represented according to biogeographic units (“W”, “C” or “E”) in each tidal level. (b) Quadrats are represented according to coastal morphology (cliff or wave-cut platform) in each tidal level and in each biogeographic unit.

Species composition was influenced significantly by physical units and coastal morphology, although R values were in general low (Table 6.3). It is especially remarkable the greater differences in the middle intertidal level between centre and eastern units. Nevertheless, both levels showed low differences among western and eastern units (R-statistic = 0.18).

Table 6.3. Results of two-way ANOSIM tests performed at each tidal level with units and coastal morphology factors. Pairwise comparisons within the factor units are also shown.

	Lower intertidal		Middle intertidal	
	R	*p*	R	*p*
Units (Global)	0.20	0.002	0.29	0.001
W vs. E	0.18	0.015	0.18	0.013
W vs. C	0.17	0.013	0.41	0.001
C vs. E	0.33	0.009	0.64	0.001
Coastal morphology (Global)	0.25	0.001	0.18	0.001

Similarity patterns for physical and biological variables could be distinguished by considering the component planes (Figures 6.7 and 6.8). Those variables with a strong correlation appear as component planes that are closest together. In the interpretation of species covers it has to be noted that the highest values (red colour) vary among species, depending on each species absolute lowest and highest covers per site. Some taxa (*Bifurcaria bifurcata* in the lower intertidal and *Corallina officinalis/Ellisolandia elongata* in both levels) were abundant throughout the study area, and colours represent where the covers were very high or just high. In other cases, species did not appear in some locations and the blue colour represent absence of the taxa (*Asparagopsis armata*, *Caulacanthus ustulatus, Cryptopleura ramosa, Gelidium corneum, Cladostephus spongiosus* and *Stypocaulon scoparium* in the lower intertidal, *Chondracanthus acicularis, Cladophora rupestris, Falkenbergia rufolanosa, Gelidium spinosum, Hildenbrandia rubra, Leathesia marina, Lithophyllum tortuosum, Mesophyllum lichenoides, Pterosiphonia complanta* and *Ralfsia verrucosa* in the middle intertidal and *Osmundea pinnatifida* in both levels).

In the lower intertidal, five groups could be identified (Figure 6.7): i) in the top of the graph average SST was related with higher abundance of *C. officinalis/E. elongata*, *G. corneum* and *P. complanata* species, where the temperature presented high values (unit E), and with higher abundance of *B. bifurcata* and *S. Scoparium,* where the temperature is low (units W and C); ii) in the left part of the graph, high P99 SST and low wave height were related with *A. armata*, *Ceramium* spp. and *C. acicularis* (unit E); iii) *C. spongiosus* and *O. pinnatifida* presented high covers in the unit W, coinciding with low values of maximum PAR and P99 SST. At the same time, maximum PAR showed positive correlations with *G. spinosum* (unit E) and negative with *M. lichenoides*, which was also related with high wave height; iv) in the left bottom part of the graph radiation was related with high covers of *Lithophyllum incrustans*, *C. ramosa*, and *Cystoseira tamariscifolia*, and with low covers of *C. ustulatus* and *F. rufolanosa*, which, in any case was widespread distributed throughout the study area; and v) in the right bottom of the graph the species *Cystoseira baccata*, *Codium tomentosum* and *Ulva* spp. were linked with the highest values of minimum SST (related with unit W the two first ones and with unit C the last one).

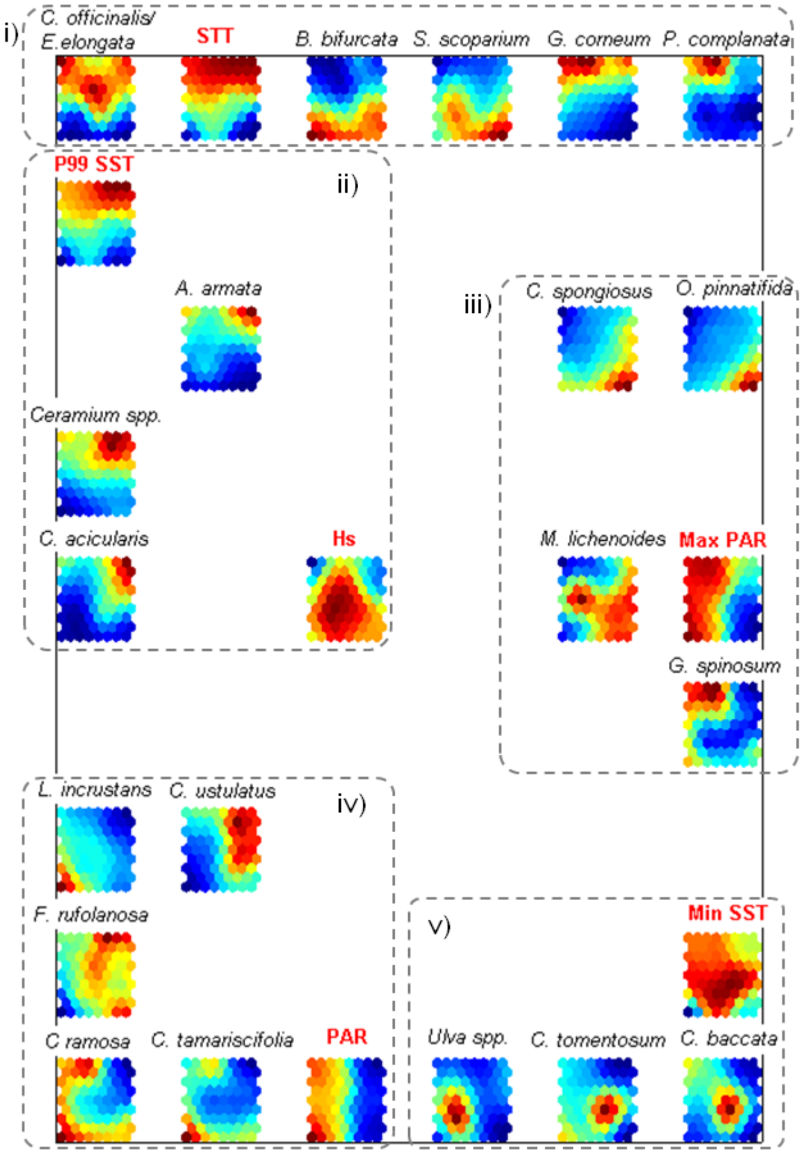


Figure 6.7. Component planes ordering of the physical variables and taxa in the lower intertidal. Visualization of variables in a red (high values) to blue (low values) scale on the previously trained SOM.

In the middle intertidal five groups were distinguished (Figure 6.8): i) the variable wave height was related with several taxa, such as *C. officinalis/E. elongata* spp. that presented high cover when exposure to wave action was high (unit C), and *G. spinosum, R. verrucosa*, *F. rufolanosa* and *B. bifurcata* that showed the opposite pattern, coinciding more or less with unit E, while *P. complanata* and *Ceramium* spp. were abundant where wave height values were medium or low; ii) the radiation was positive correlated with *Gelidium pusillum* (unit C) and negative with *C. ustulatus*, *C. acicularis* and *C. tomentosum*; iii) in the centre part of the graph *Ulva* spp. was related with the highest values of minimum temperature; iv) *L. incrustans* and *C. rupestris* appeared with a higher cover when both mean and P99 sea surface temperature were elevated (unit E), while *H. rubra* and *S. scoparium* presented lower cover with these conditions (unit W); and finally v) species *L. marina*, *M. lichenoides*, *L. tortuosum* and *O. pinnatifida* showed higher covers in the western units where the maximum PAR was low.

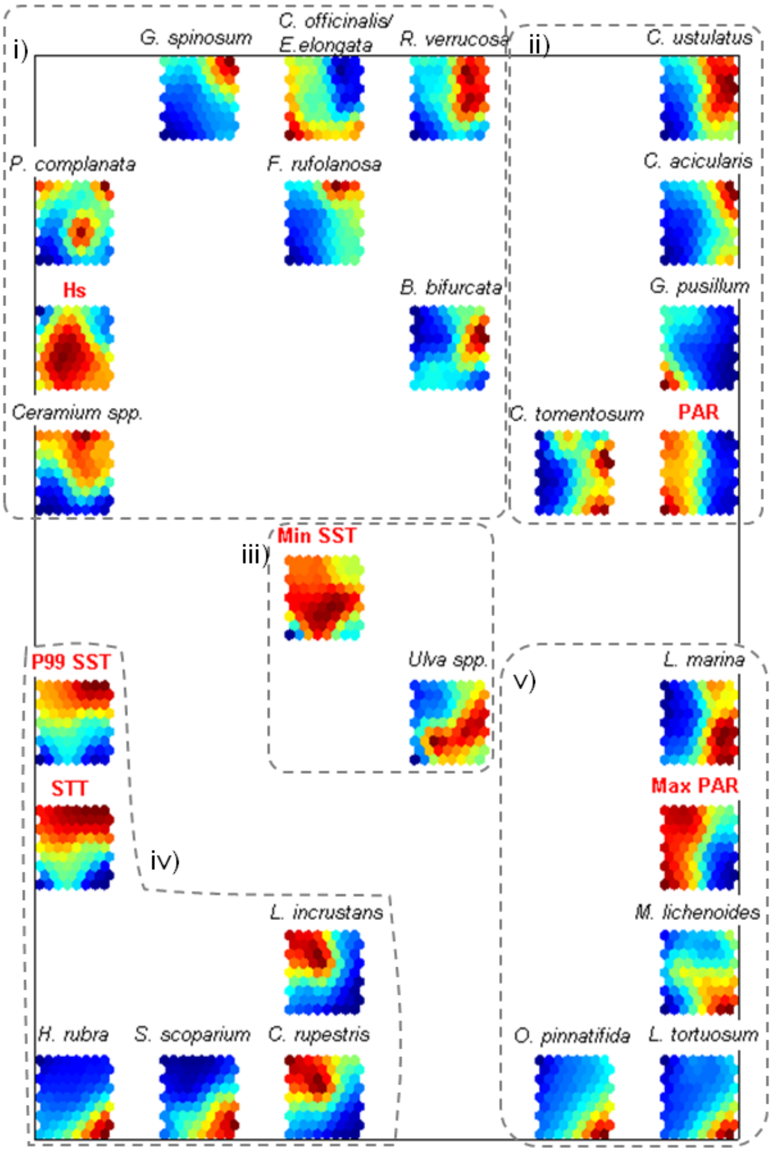


Figure 6.8. Component planes ordering of the physical variables and taxa in the middle intertidal. Visualization of variables in a red (high values) to blue (low values) scale on the previously trained SOM.

The main species composition of the three units obtained is described hereafter (graphical representation of quadrats in Figure 6.9).

- W (Western coast): in the lower intertidal *Bifurcaria bifurcata* was the dominant taxa, accompanied by *Stypocaulon scoparium* and *Corallina officinalis/Ellisolandia elongata*. The middle intertidal was clearly dominated by *C. officinalis/E. elongata*, as the whole study area, and *Caulacanthus ustulatus, Ulva* spp. and *S. scoparium* were the main accompanying taxa.

- C (Centre coast): the lower intertidal was also dominated by *B. bifurcata*, with *S. scoparium* and *C. officinalis/E. elongata*. The middle intertidal was characterized by *C. officinalis/E. elongata*, accompanied by *Ulva* spp., *Ceramium* spp., *C. ustulatus* and *S. scoparium*.

- E (Eastern coast): the lowest belt was characterized by the dominance of *Gelidium spinosum*, along with *C. officinalis/E. elongata*, *B. bifurcata* and *Gelidium corneum*, and the rest of the lower intertidal was dominated by *C. officinalis/E. elongata* and accompanied by *B. bifurcata, G. spinosum and G. corneum.* In the middle intertidal *C. officinalis/E. elongata* was again the dominant taxa, with *Litophyllum incrustans, C. ustulatus, Chondracanthus acicularis* and *Ceramium* spp.

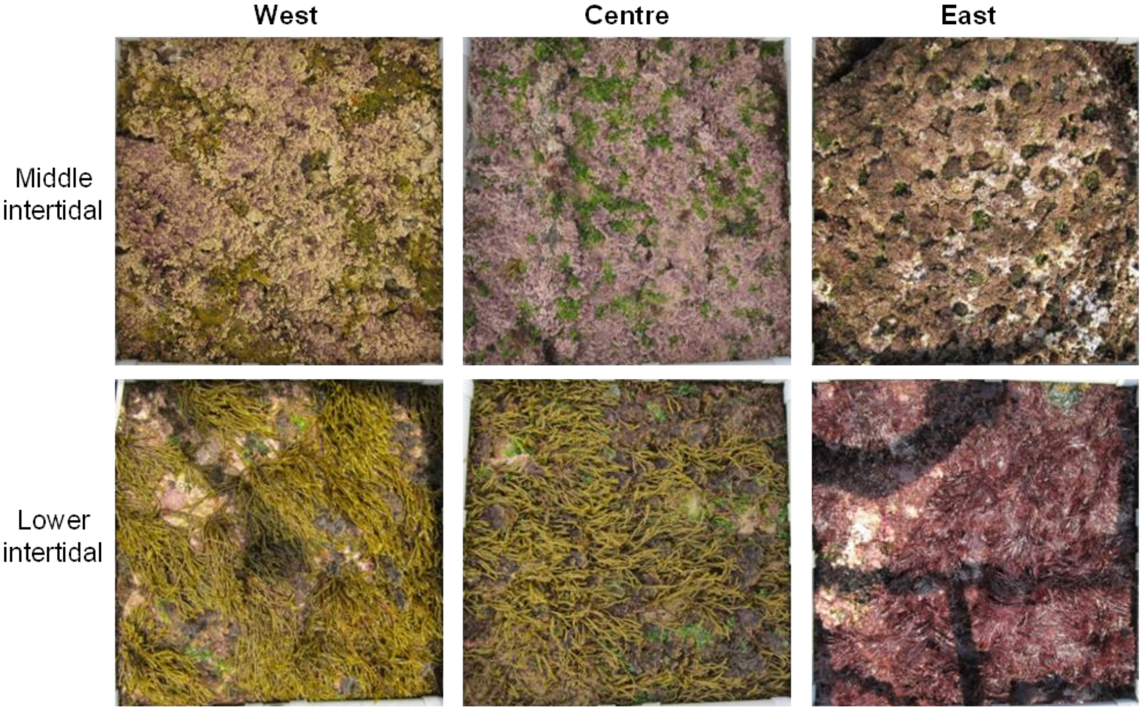


Figure 6.9. Type photographs (quadrats of 50 x50 cm) of each unit and intertidal level.

6.4. Discussion

In this work, a hierarchical classification along the NE Atlantic coast has been completed focusing on the local scale (coast of Cantabria). This way, detailed knowledge about both the distribution of intertidal macroalgae communities and its abiotic environment is available at European (Ramos et al., 2012; 2014), regional (Ramos et al., in press) and local scale. The multi-scale approach developed has the potential to successfully reach the suitable detail for particular applications, consistent with the management activity considered in each case (Christensen et al., 1996). Thus, it is critical to adequate methodologies (data acquirement, statistical analysis, etc.) to each level of definition.

Ecological studies and resource management of coastal waters typically occur at local to regional scales (Richmond and Stevens, 2014), being the finer levels of classification usually the most necessary and, thus, the critical ones (Valesini et al., 2010). However, it is difficult to find local classifications based on standardized data and objective decision rules. In this sense, here is demonstrated the feasibility of using physicochemical variables obtained by satellite sensors and numerical modelling, easily quantitatively measured data that provide an objective classification system from lower to higher levels of resolution. It has to be noted that physical indicators present, in general, a low range of variation along a reduced study area, as is the one of this study. However, the combination of them in the statistical classification provides a suitable environmental characterisation of the coast with ecological meaning.

The zonation patterns along the intertidal correspond, in general, with those described in other near areas: Asturias (Fernández and Niell, 1982; Anadón, 1983), Basque Country (Borja et al., 1995; Díez et al., 1999) and locate areas inside Cantabria as Mouro Island (Puente, 2000; Juanes et al., 2008). In the middle intertidal, *Corallina officinalis/Ellisolandia elongata* forms a continuous carpet, being the dominant taxa all along the coast of Cantabria. Below this there is a fringe structured by *Bifurcaria bifurcata*, although towards the East *Gelidium spinosum* and *C. officinalis/E. elongata* are the dominant taxa (Borja et al., 1995). Regarding the longitudinal distribution, inside the coast of Cantabria it is observed the general pattern described along the North Iberian Peninsula, where from the West towards the East Ochrophyta decrease and the presence of Rhodophyta species stands in the lower intertidal and shallow subtidal (Fischer-Piette, 1955; Anadón, 1983; Borja et al., 2004; Gorostiaga et al., 2004; Ramos et al., in press).

Despite this general pattern, the highest differences in species composition are not found between the two extremes of the coast, despite what can be expected according to a potential biogeographic gradient, but between the centre (unit C) and the eastern area (unit E). This seems to be caused by the exposure to wave action, since this variable clearly differs between these two zones, reaching the highest values in unit C and the lowest in unit E. On the other hand, the sea surface temperature does follow the expected pattern, increasing from the western to the eastern study area, following a trend that is largely known at a smaller scale along the North of the Iberian Peninsula (c.f. Ramos et al., in press). This way, at local areas the distribution of macroalgae species seems to be more affected by exposure to wave action than by temperature, in contrast to what happens along broad regions (van den Hoek, 1982a; Breeman, 1988; Lüning, 1990; Ramos et al., 2014).

The interaction between the environment and macroalgae communities at a local scale is an essential element of this study, including the knowledge about the relation between each physical variable and macroalgae species. Regarding exposure to wave action, we have identified some associations that have also been reported in other areas. Such is the case of *Pterosiphonia complanata*, *Ceramium* spp., *B. bifurcata* and *Chondracanthus acicularis* in the lower intertidal and *G. spinosum* in the middle intertidal, more abundant in shelter to semi-exposed shores (Dixon and Irvine, 1977; Bárbara and Cremades, 1987; Cabioc'h et al., 1995; Puente, 2000). As well as *Mesophyllum lichenoides* in the lower intertidal and *C. officinalis/E. elongata* in the middle one related with high exposure to wave action (Stewart, 1989; Irvine and Chamberlain, 2011; Díaz-Tapia et al., 2013). Thus, as previously mentioned, some of the most clear patterns observed at local scale in rocky assemblages may be explained by wave exposure (Díaz-Tapia et al., 2013).

In the case of radiation, specific connections between PAR and specific taxa distribution are rarely found in bibliography, although the effect of this variable in macroalgae is largely known (e.g., Häder and Figueroa, 1997; Bischof et al., 2002). Along the coast of Cantabria, the associations found in both lower and middle intertidal were a higher cover of *Osmundea pinnatifida* and *Caulacanthus ustulatus* where PAR was low, and the contrary in the case of *M. lichenoides*.

In regard to temperature, large biogeographic patterns are not comparable to relations found in this study. However, these relations can be compared to the results obtained in the previous work developed at a regional scale along the N and NW Iberian Peninsula (Ramos et al., in press). Some of the most abundant characteristic taxa (*C. officinalis/E. elongata*, *B. bifurcata* and *Stypocaulon scoparium*) showed similar patterns related with temperature at both scales (positive relation the first one and negative the last two). On the other hand, opportunistic taxa (*Ceramium* spp. and *Ulva* spp.) presented different relations with this factor at regional and local scale, what suggests that these taxa are ubiquitous and do not have specific preferences for SST along these regions.

In any case, similar patterns observed between physical variables and species in the component planes analysis have to be examined with caution, since relationships could not be necessarily causal, but due to variables correlation with unmeasured factors. For example, bathymetric and topographic features in each specific point could cause local modifications. On the other hand, biological interactions, as competition or predation, are important factors affecting species distribution at local scale, especially in the lower intertidal (Janke, 1990; Nybakken, 1997). But these factors are difficult to assess and quantify at the level required for this study and have not been included in the classification.

The relation between coastal geomorphology and intertidal macroalgae community composition has been already showed in the coast of Cantabria (Ramos et al., submitted). The addition of this variable provides a more detailed environmental characterisation and allows us to explain better the distribution of macroalgae species. Depending on the purpose (i.e., type of the study, assessment or conservation plan) the addition of this variable could be necessary or not. Thus, the hierarchical approach is very useful, providing the option to decide in each case if the classification accuracy increase is required. However, given the few samples of each subunit, it is difficult to determine if differences in species distribution are caused by the influence of coastal geomorphology or by the variation among sampling sites driven by other environmental factors.

In the framework of temporal variability, one of the applications of the ecological classification obtained is to gather data on the current ecological status and understanding future changes in the communities (Sales and Ballesteros, 2009). The inclusion of the mete-oceanographic variables (SST, PAR, Hs) is advantageous, allowing to detect possible changes in the distribution of macroalgae communities due to climate change (Martín-García et al., 2013). In this sense, the North coast of the Iberian Peninsula is a very interesting area where the distribution limits of cold temperate species have moved along a longitudinal gradient during the last century (Sauvageau, 1897; Fischer-Piette, 1957; Fischer-Piette, 1963; Anadón and Niell, 1981; Fernández and Niell, 1982; Fernández, 2011; Díez et al., 2012; Duarte et al., 2013). The most recent movements are westward regression of kelps associated with the increased in maximum sea surface temperature from 1970 onwards (Planque et al., 2003; Gómez-Gesteira et al., 2008; Anadón et al., 2009; deCastro et al., 2009). Thus, the absence of a belt dominated by *Laminaria ochroleuca* and *Saccorhiza polyschides* in the whole study area is in agreement with this shift (Fernández and Niell, 1982; Anadón, 1983). Taking into account the great importance of temporal variability related with biological communities modifications, the next step in the development of ecological classification systems should be to include annual and seasonal variation of environmental variables or climatic index (e.g., NAO, ENSO), providing a comprehensive tool for a host of ecological and management applications (Carballo et al., 2002; Straile and Stenseth, 2007).

In conclusion, the classification developed in this work complete a hierarchical framework to classify the NE Atlantic coast, a promising standard approach that allows to apply the most suitable resolution according to the study extension and that could be applicable to a wide range of coastal areas. The hierarchical approach adopted for the local scale divides the coast into three environmental units or five subunits by the addition of coastal morphology, providing the possibility of adopting the scheme more appropriate for the study or management purpose. These units and subunits support different macroalgae assemblages. In general, in the lower intertidal, *Bifurcaria bifurcata* and *Stypocaulon scoparium* dominate the western and centre areas, while *C. officinalis/E. elongata* and *Gelidium* spp. are most abundant towards the East. On the other hand, throughout the middle intertidal *C. officinalis/E. elongata* is the dominant taxa. These patterns in species distribution observed at local scale seem to be explained mostly by the exposure to wave action. The classification methodology could be used as a useful tool in environmental management of coastal waters, including the impact assessment of anthropogenic pressures or the vulnerability of macroalgae communities to climate change.

Chapter VII

General conclusions and future research

Chapter VII. Conclusions and future research

7.1. Conclusions

The overall aim of this thesis was to develop a methodology for the classification of intertidal rocky shores at different spatial scales in order to obtain a tool to deal with assessment criteria and conservation strategies.

To realize this aim and the specific objectives, a rocky coastal classification system has been established at three levels: the European scale (NE Atlantic), the regional scale (N and NW Iberian Peninsula) and the local scale (Cantabria). The proposed methodology is based on the analysis of the abiotic characteristics that determine the distribution of macroalgae species. Through this analysis, data obtained by specific procedures (e.g., satellite data and numerical modelling) after statistical treatment (e.g., cluster, SOM, k-means) could be applied to obtain groups with ecological significance characterised by different communities and species distribution.

The results obtained allow the extraction of general conclusions regarding the coastal classification system and the distribution of macroalgae communities, as well as specific conclusions derived at each spatial scale. Thus, the following conclusions are drawn firstly for the whole classification system, and then specific conclusions are summarized for each of the four working chapters.

General conclusions

- The methodological approach proposed allows to establish a classification system of the coastal environment and to recognize the physical and biological variability associated with each group at different scales. This classification system offers an objective statistical tool for the definition of ecologically relevant regions.

- The quantification of variables by means of satellite sensors and numerical modelling offers a useful approximation and promises a great future because of its unique viability dealing, specially, with global scale studies.

- The classification system developed defines a hierarchical framework to classify the NE Atlantic coast, a standard approach that allows applying the most suitable resolution according to the study extension and that could be applicable to a wide range of coastal areas.

- The ability of the classification system to identify environmental and species distribution gradients at different scales shows the suitability of adapting the methodologies to specific spatial requirements.

- The classification system may be a useful tool for environmental protection and for the assessment of anthropogenic effects and climate change in coastal ecosystems. In addition, the knowledge obtained about the relationships of species with environmental factors will be helpful for decision-making on the management and conservation of natural resources, offering a procedure to predict the composition and structure of sustainable systems over space and time.

Physical classification at European scale

- The main groups obtained were the biotypes A1 (Canary Islands and Madeira), A2 (Iberian Peninsula, South France and Azores), B1 (continental coast of the North Sea, including Helgoland island, and Kattegat and Skagerrak areas until Rogaland (Norway)), B21 (UK and Republic of Ireland) and B22 (Trøndelag and Northern Norway regions). The variability of environmental conditions among these broad geographic regions is recognized through the subtypological variants.

- It is possible to assume that the proposed physical classification would be able to represent the distribution of marine species along the NE Atlantic region.

Biological validation at European scale

- This study confirms the biological relevance of the physical coastal classification established in the previous section.

- The procedure applied allows the detection of the most representative macroalgal taxa along the study area, the selection of those that may define biogeographic differences and the validation of the ecological suitability of the physical classification.

- The distribution of intertidal macroalgae shows both latitudinal and longitudinal gradients related with physical factors. The latitudinal gradient is most important and is mainly associated with the sea surface temperature gradient.

- Though it is difficult to establish clear distributional borders in a natural environment, it seems clear that there is a transition biogeographical area around Brittany (France), which separates the southern from the northern area of the NEA coast. In addition, within the northern area there is another marked boundary, which differentiates between northern France, UK and Ireland and the rest of the coast.

Coastal classification at regional scale

- Regarding specific results along the N and NW Spanish coast, four coastal typologies were defined: Lower Rias (typology A, from the Portuguese border to Finisterre Cape), Upper Rias (typology B, from Finisterre Cape to Ria de Vivero in Lugo), W Cantabric (typology C, from Ria de Vivero to Peñas Cape) and E Cantabric (typology D, from Peñas Cape to the French border).

- The ecological meaning of the typologies has been confirmed in the lower and middle intertidal, where seaweeds are a structural element. There is a clear difference between the Upper Rias typology and the rest of N and NW Iberian

Peninsula coast, showing a gradient, as previously reported in literature, caused mainly by temperature and exposure to wave action.

The role of geomorphology in macroalgae distribution at local scale

- The geomorphological variables show a relation with the intertidal macroalgae patterns at a local scale. However, these variables do not seem to be the most determining agents because, in most cases, they are related to other factors that, ultimately, define the distribution of species in the different levels of the intertidal.

- Regarding descriptive parameters, specific richness is related to the orientation of the coast and this index together with diversity are related to active processes in the middle intertidal zone.

- The community composition varies according to coastal morphology in the lower intertidal and to coastal orientation in the middle level.

- Several species show substrate preferences, such as *Bifurcaria bifurcata* that appears in wave-cut platforms oriented towards the East, or *Corallina officinalis/Ellisolandia elongata* and *Gelidium spinosum*, which are found in cliffs oriented towards the North and West.

Coastal classification at local scale

- The hierarchical approach adopted for the local scale divides the coast into three environmental units (West, Centre and East) and five subunits by the addition of the variable coastal morphology (West-cliffs, West-wave-cut platforms, Centre-cliffs, Centre-wave-cut platforms and East). The level of definition that is more appropriate for each study or management purpose could be adopted.

- These units and subunits support different macroalgae assemblages. In general, in the lower intertidal, *Bifurcaria bifurcata* and *Stypocaulon scoparium* dominate the West and Centre units, while *Corallina officinalis/Ellisolandia elongata* and *Gelidium* spp. are most abundant towards the East unit. On the other hand, throughout the middle intertidal *C. officinalis/E. elongata* is the dominant taxa.

- The patterns in species distribution observed at local scale seem to be explained mostly by the exposure to wave action.

7.2. Future research

The studies carried out in this thesis have revealed the existence of certain aspects that could be improved in the procedures described to achieve the objectives, as well as the possibility of exploring new aspects in the complex field of ecological classification systems. These issues to explore further have been analyzed in detail in the discussion section of each chapter, followed by possible solutions. Hereafter, the most relevant aspects of the thesis awaiting future research are summarized.

- Regarding the physical variables, the incorporation of different factors in the classification system should be studied. To perform this challenging task, the interaction among experts of different disciplines (e.g., ecology, oceanography, meteorology) may substantively improve the development of new ecologically sound physical variables that are suitable for classifications at different scales. Moreover, the availability of data at finer temporal scales (e.g., hourly data of SST) may facilitate hypothesis testing on ecological interactions. On the other hand, the high availability of wave height data from numerical modelling raises the possibility of using more specific wave energy variables in future approaches, such as the bottom shear stress or the frequency of extreme events, which have greater explanatory potential for the important interaction between wave energy and organisms (Hiscock, 1983; Gaylord, 1999).

- Regarding the classification at the NE Atlantic scale, further information on the distribution of macroalgae species should be obtained. Standardized quantitative data from homogenous sampling in the entire area will allow to characterise in detail the composition of communities and to carry out a more precise biological validation. In this way, a more specific assignment of biotypes of certain coastal areas (e.g., Celtic and North Sea related areas from the UK or the Skagerrak area) could be justified.

- Furthermore, possible regional or local singularities should be considered inside the NE Atlantic coast. Specific analyses of possible particular characteristics may be needed (e.g., salinity in Skagerrak and Kattegat areas).

- The dominance of fauna species in the higher intertidal underscored the limited contribution of macroalgae to the validation of physical typologies at this level. Thus, other organisms, such as molluscs or arthropods, could be considered for further biological validation. On the other hand, subtidal macroalgae could provide a more robust ecological meaning to the physical classification.

- An additional scale could be developed. In this scale the study area will be an even more restricted zone, where species associations could be studied in detail and related to specific factors such as shade, slope, roughness, sedimentation, presence of pools, etc.

- The temporal influence should be included in the analysis, relating the distribution of macroalgae species with seasonal or annual variability of physical variables or with climatic indexes (e.g., NAO, ENSO), providing a comprehensive tool for a host of ecological and management applications (Carballo et al., 2002; Straile and Stenseth, 2007). This study may reveal the progression or regression of individual species in accordance to temporal variation, information useful to test hypotheses on climate change. By doing this, a model to predict trends under specific climate change scenarios at different scales could be developed.

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