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Chapter 5

The Bay of Biscay

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5.1 DESCRIPTION OF THE AREA

The Bay of Biscay is located in the temperate (NE) North-East Atlantic Ocean, between (NW) North-West France (offshore of Brittany) and NW Spain (Galicia) (Fig. 5.1). The Bay is included in the Lusitanian province and within the South European Atlantic Shelf ecoregion (Spalding et al., 2007). The name of this ecoregion is also used in the European Marine Strategy Framework Directive (MSFD) and includes the Bay of Biscay and the Iberian coasts. The limits of the Bay are Cape Finisterre, at 43°N, in Galicia (NW Spain), and 48°N, in Brest (NW France) (Lavín et al., 2006). In total, the Bay occupies around 175,000 km^2.

The Bay of Biscay is a well-differentiated geomorphological unit, orientated toward the NW. The abyssal basin, which represents around 50% of the total surface, has a mean depth of 4800 m, being adjacent to the Porcupine plain in the northern part, but separated from the Iberian Abyssal Basin and the West Iberian Margin by the Charcot Seamounts and the Galician Bank (Lavín et al., 2006). In turn, the continental shelf in the south of the Bay is quite narrow (between 12 and 30 km), being much wider on the French coast, especially in the north, where it can be more than 150 km wide. The continental slope, an area of transition between the shelf and the deep sea, is very pronounced, with a slope of the order of 10%–12%, even more in the south-eastern part. The slope is formed by three main areas with different orientation, the Armorican slope NW–SE, the Aquitaine slope N–S, and the Cantabrian slope with an E–W orientation. This slope is cut by numerous canyons, which have generally narrow, steep-sided, linear, and sinuous channels, the most conspicuous being the Cap Breton Canyon, where the 1000 m isobath is found only 3 km from the coast (Lavín et al., 2006). The deep-sea valleys allow continental sediments to be transported to oceanic basins from the main rivers (Vilaine, Loire, Gironde, and Adour), all of them in France, while the rivers in northern Spain are shorter and with small flows.

5.2 SEASONALITY AND NATURAL ENVIRONMENTAL VARIABLES

5.2.1 Climate and Teleconnection Patterns

Winds control upwelling in the Bay of Biscay (Alvarez et al. 2011; García-Soto & Pingree, 2012), driving currents (Pingree, 1993; Fontán & Cornuelle, 2015; Caballero et al., 2016; García-Soto & Pingree, 2012; Kersale et al., 2016), river plume spread (Puillat, Lazure, Jégou, Lampert, & Miller, 2004; Costoya et al., 2016) and wave propagation (Bertin, Li, Roland, & Bidlot, 2015). Atmospheric circulation at mid latitudes in the North Atlantic, (in the Bay of Biscay in particular), is mainly governed by the existence of a high-pressure area (the *Azores High*) and a low-pressure area (the *Iceland Low*). Consequently, winds tend to have a marked eastward component. The position of both centers varies seasonally; thus, the high drifts south-eastward in winter and north-westward in summer. Wind roses are depicted in Alvarez, Gomez-Gesteira, deCastro, and Carvalho (2014) who used buoy data at different locations in the Bay. The Gascogne buoy, located in the middle part of the bay (45.20°N, 5°W), shows the prevalence of intense westerlies. Northeast and north winds are also observed, but with lower frequencies. Similar patterns are observed at the buoys located near the shore (Bares, Cape Peñas, and Bilbao), which predominantly shows two wind patterns, easterlies and westerlies, indicating that coastal winds tend to be aligned with topography.

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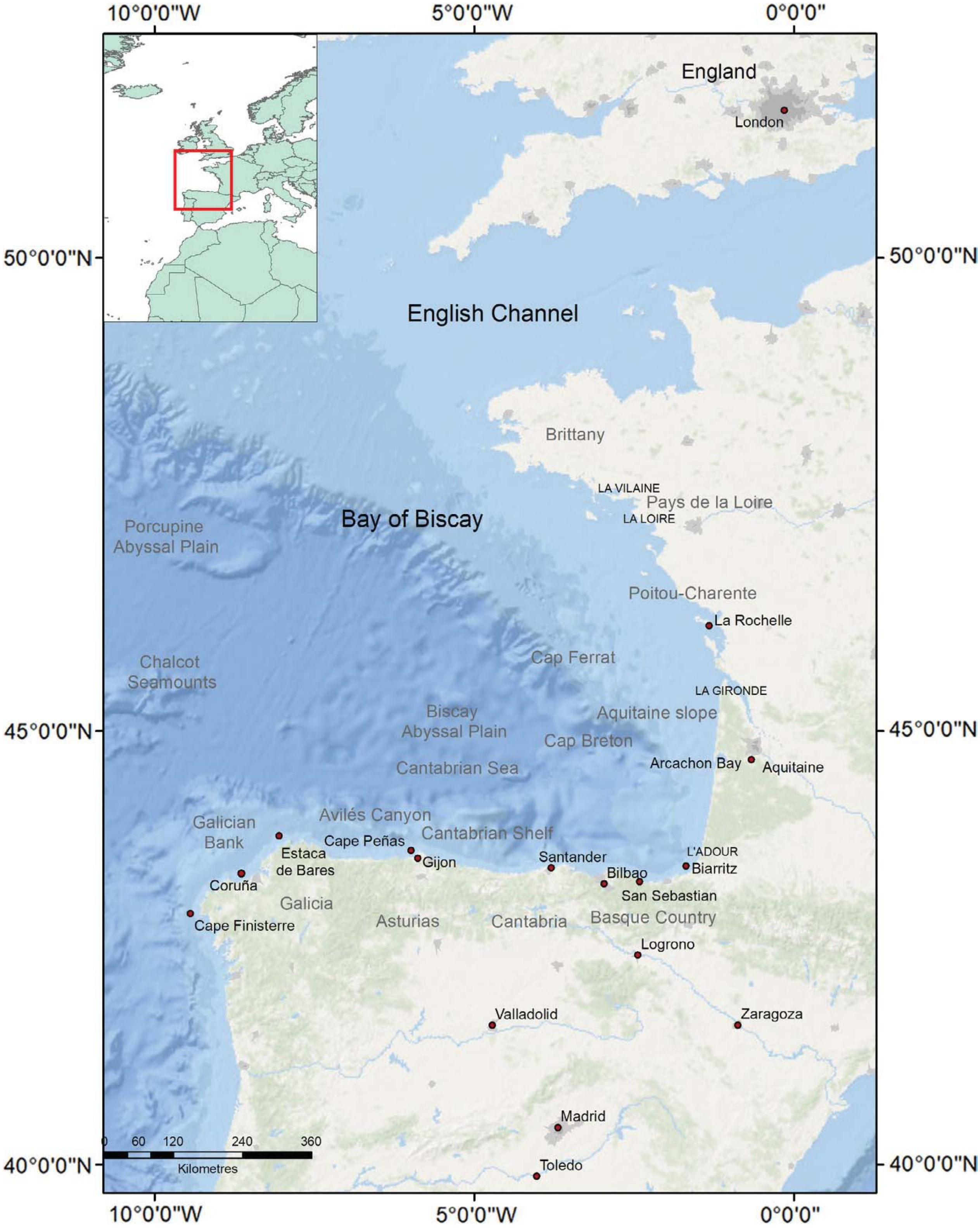

FIG. 5.1 Map of the Bay of Biscay, showing the main biogeographical characteristics and the locations mentioned in the text.

TABLE 5.1 Climatic Data (1981–2010) Along the Spanish and French Coasts, Provided by AEMET (Spanish Agency of Meteorology) and Météo-France

Locations	T_{max}/Month	T_{min}/Month	T_{annual}	R_{max}/Month	R_{min}/Month	R_{annual}
Spain						
Coruña	19.1/Aug	9.3/Jan	13.8	144/Dec	35/Jul	1014
Asturias	18.8/Aug	9.4/Jan	13.5	134/Nov	47/Jul	1062
Santander	20.3/Aug	9.7/Jan	14.5	157/Nov	52/Jul	1129
Bilbao	20.9/Aug	9.3/Jan	14.7	147/Nov	50/Jul	1134
Hondarribia/San Sebastián	21.5/Aug	8.9/Jan	14.8	188/Nov	85/Jul	1649
France						
Biarritz	21.3/Aug	8.4/Jan	14.3	186/Nov	69/Jul	1450
Bordeaux	21.3/Aug	6.6/Jan	13.8	110/Nov	50/Jul	944
La Rochelle	20.3/Aug	6.4/Jan	13.2	94/Nov	40/Jun	759
Nantes	19.6/Aug	6.1/Jan	12.5	97/Dec	43/Jun	820
Brest	20.8/Aug	6.9/Jan	11.5	147/Dec	59/Jul	1205

Temperature (T) in °C, rainfall (R) in mm.

According to the Köppen–Geiger classification, the region shows a *cfb* climate (temperate with precipitation in all seasons). The mean temperature and precipitation at the main coastal locations along the Bay of Biscay are shown in Table 5.1. A clear annual cycle is observed for both variables, with maximum temperatures in August and minimum temperatures in January; maximum precipitations in November–December and minimum in June–July. Along the Spanish coast, the annual temperature range is of the order 9.5–12.5°C, increasing eastward due to warmer summers in the inner part of the Bay. The range of temperature is slightly higher along the French coast (~13.5°C) without a clear latitudinal trend. Precipitations correspond to an oceanic climate and range from 759 mm per year in La Rochelle to 1649 mm per year near San Sebastian (Table 5.1.).

Teleconnection patterns are recurring and persistent, with large-scale patterns of pressure and circulation anomalies spanning vast geographical areas. The most studied indices in the Bay of Biscay are the North Atlantic Oscillation (NAO) and the East Atlantic Pattern (EA). NAO consists of a north–south dipole with one center located over Greenland and the other at central latitudes (35°N–40°N) in the North Atlantic. The EA pattern is similar to the NAO pattern with the anomaly centers displaced southeastward to the approximate nodal lines of the NAO pattern. Both patterns have been shown to be related to the most important oceanographic features in the Bay.

According to García-Soto and Pingree (2012), NAO is a high-frequency climate oscillation that exerts some control over specific years with extreme changes. EA can explain around 25% of the sea surface temperature (SST) variability. Michel, Treguier, and Vandermeirsch (2009) stated that the first mode of interannual SST variability is related to the inverse winter NAO index. García-Soto, Pingree, and Valdés (2002) pointed out that winter warming in the southern Bay of Biscay during *Navidad* years was correlated with low values of the NAO Index for the preceding months (November–December). Cabrillo, González-Pola, Ruiz-Villarreal, and Montero (2011) analyzed the relationship between heat flux anomaly and NAO showing that long—term trends in the mixed layer depth (MLD) are related to the decadal variability of NAO. In addition, intense mixing and cooling observed in the winter of 2005 is related to the negative phase of EA. Gómez-Gesteira, deCastro, Santos, Álvarez, and Costoya (2013) analyzed changes in the Eastern North Atlantic Central Water (ENACW), observing that trends in salinity and temperature are consistent with changes in EA. Prieto, González-Pola, Lavín, and Holliday (2015) observed that years with a strong winter NAO index are characterized by shifts in thermohaline properties at intermediate levels. One example is the increase in temperature and salinity that followed the abrupt drop in the NAO index that took place in 2010. Costoya et al. (2016) found that SST is positively correlated with NAO only in the area affected by the Loire and Gironde waters. Aravena, Villate, Iriarte, Uriarte, and Ibáñez (2009) analyzed the Basque coast showing that air temperature is negatively correlated with NAO; nevertheless, no correlation was found with rainfall. Other authors like Dupuis, Michel, and Sottolichio (2006) affirm that the NAO index is negatively correlated with the discharge of the Garonne (Gironde) River.

Sea waves are also influenced by teleconnection patterns. Martínez-Asensio et al. (2016) found a positive correlation between wave period and NAO. They also found that wave direction shifts counterclockwise with positive NAO and negative EA. Le Cozannet et al. (2011) found that sea states are related to pressure anomalies induced by NAO and EA. In addition, Dupuis et al. (2006) found that NAO is positively correlated with the wave period.

The link with modes can also be observed at the environmental level. Thus, Beaugrand, Ibañez, and Reid (2000) related changes in plankton with NAO, whereas Signa, Cartes, Solé, Serrano, and Sánchez (2008) studied the ecology of a swimming crab in Galician and Cantabrian Seas, observing that the interannual abundance seems to be controlled by NAO, and Borja, Fontán, Sáenz, and Valencia (2008) found that 50% of the variability in anchovy recruitment is related to the EA pattern.

5.2.2 Oceanographic Features

5.2.2.1 River Discharge

River discharge is the main source of freshwater flowing into the Bay of Biscay. Rivers in the Cantabrian shelf are short and flow swiftly, although with a small runoff due to the proximity of mountain ranges to the coast. These together supply a mean freshwater discharge of 400 $m^3 s^{-1}$. Loire and Gironde are the two main rivers in the Bay of Biscay, providing around 80% of the freshwater discharge onto the French shelf. Their mean discharge is on the order of 900 $m^3 s^{-1}$ with a marked annual cycle, reaching mean maximum values higher than 1200 $m^3 s^{-1}$ in January and mean minimum values lower than 500 $m^3 s^{-1}$ in August. Adour is an intermediate river with a mean runoff on the order of 350 $m^3 s^{-1}$ and with an annual cycle similar to Loire and Garonne.

River plumes have been analyzed during the past few years. González-Nuevo and Nogueira (2014) studied the Cantabrian plumes using in situ data and the plumes of Loire and Garonne were analyzed by Puillat et al. (2004), Charria, Lamouroux, and De Mey (2016), Alvera-Azcárate, Barth, Parard, and Beckers (2016), and Costoya et al. (2016). The plume extension is especially large from November to February, although it does not necessarily follow the river discharge, especially during the spring months when winds tend to dilute the plume (Costoya et al., 2016).

5.2.2.2 Water Masses

Water masses in the Bay of Biscay are well known, thanks to significant research conducted during the eighties and nineties (Table 5.2.).

In addition, some authors (Botas, Fernández, Bode, & Anadón, 1989) also consider the existence of a particular branch of the ENACW in the Bay of Biscay, although this idea has nowadays been discarded by most of the community.

A special feature observed in the middle part of the French shelf (north of 46°N) is the so-called cold pool (*Bourrelet froid*) (Koutsikopoulos & Le Cann, 1996; Puillat et al., 2004). This cold water mass is found below the thermocline, from 40 to 50 m to the bottom, and shows a nearly homogeneous temperature (11–12°C) during most of the year. Despite its homogeneity at the annual scale, the cold pool shows a remarkable interannual variability.

TABLE 5.2 Main Water Masses in the Bay of Biscay

Water Mass	Depth (m)	Potential Temperature (°C)	Salinity	Potential Density Anomaly ($kg\,m^{-3}$)
Eastern North Atlantic central water				
Subtropical branch	<300	>12.5	>35.75	<27.05
Subpolar branch	<400	10.5–12.5	35.55–35.70	27.05–27.15
Mediterranean water				
Shallow	400–700	11.8–12.2	35.80–35.90	27.20–27.30
Upper	700–900	10.5–13.5	35.8–36.8	27.40–27.65
Lower	1000–1500	9.5–12.5	35.8–37.5	27.70–27.85
Labrador sea water	1500–3000	3.4–4.0	34.90–34.95	27.70–27.80
Lower deep water	>3000	<3.3	34.90–34.95	>27.80

Adapted from OSPAR. (2000). Quality status report 2000: Region IV: Bay of Biscay and Iberian Coast. OSPAR Commission, London. 134 + xiii p., using different sources.

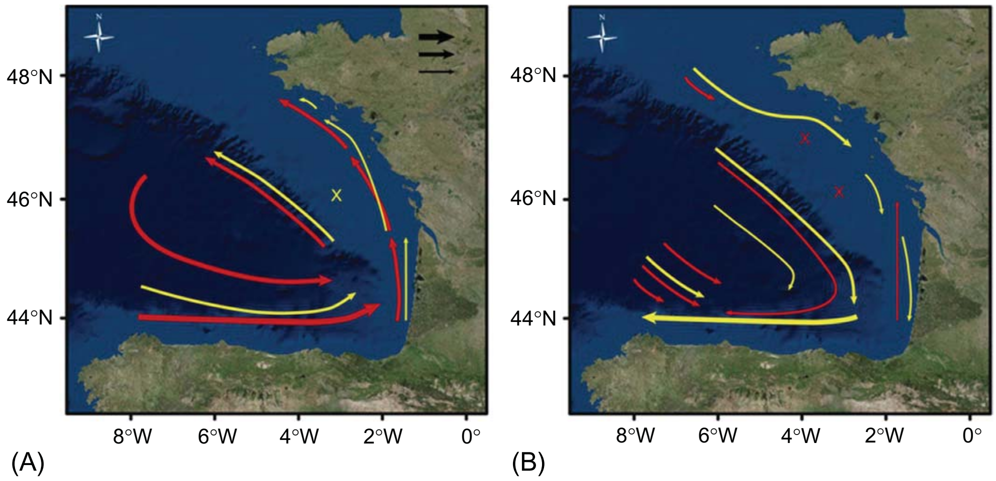

FIG. 5.2 Circulation scheme within the Bay of Biscay: (A) circulation in autumn (*red*) and winter (*yellow*), (B) circulation in spring (*red*) and summer (*yellow*). Arrow thickness is proportional to the intensity of currents, as marked by black arrows in the first frame, which corresponds to values higher than 5 cm s^{-1}, 3–5 cm s^{-1}, and 1–3 cm s^{-1}, respectively. Crosses mark slack zones. *Adapted from Charria, G., Lazure, P., Le Cann, B., Serpette, A., Reverdin, G., Louazel, S., Batifoulier, F., Dumas, F., Pichon, A., Morel, Y. (2013). Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay. Journal of Marine Systems 109, S60-S76.*

5.2.2.3 Circulation

The circulation in the Bay of Biscay is complex and depends on bathymetry, tides, density-driven currents, and wind. The main macroscopic features are summarized in the classical figure created by Koutsikopoulos and Le Cann (1996) and modified by Charria et al. (2013) (Fig. 5.2.). The oceanic area of the bay, which is part of the North Atlantic circulation, is characterized by a weak (<2 cm s^{-1}) and variable anticyclonic circulation (Koutsikopoulos & Le Cann, 1996; Pingree, 1993).

A poleward current transporting warm and salty water develops along the Atlantic coast of the Iberian Peninsula during autumn and winter (Frouin, Fiúza, Âmbar, & Boyd, 1990; Haynes & Barton, 1990). This current, which attains velocities around 25 cm s^{-1}, is trapped within a narrow band of approximately 50 km from the shelf edge and extends down to 400 m. The current is mostly density driven (Huthnance, 1984) and reaches the Cantabrian slope around Christmas, which is the reason why it was named *Navidad* (Christmas in Spanish) by Pingree and Le Cann (1992a). During summer, owing to westerly winds, a surface equatorward current can develop, which sinks and displaces offshore the slope current. For an updated study on seasonal changes in the slope current, see Charria et al. (2013).

Eddies can be formed by destabilization of the poleward current. Anticyclonic eddies tend to be longer-lasting and were named SWODDIES (Slope Water Oceanic eDDIES) by Pingree and Le Cann (1992a, 1992b). Their diameter ranges from 60 to 130 km and the mean depth is on the order of 500 m. Recent studies along the Northwestern Iberian margin (Teles-Machado, Peliz, McWilliams, Dubert, & Le Cann, 2016) have proved the dominance of anticyclonic eddies at the top 200 m of the water column and from 600 to 1000 m, as well as the dominance of cyclonic eddies from 600 to 1000 m. Eddies have been monitored in the Bay of Biscay by means of satellite and in situ data and by numerical models (Caballero et al., 2014; García-Soto et al., 2002). In addition, Ferrer and Caballero (2011) conducted a 20-year numerical simulation finding a mean migration speed of less than 2 cm s^{-1}.

Coastal upwelling has traditionally been considered one of the main oceanic features along the western Iberian, but it has received much less attention along the Cantabrian Sea (Botas, Fernández, Bode, & Anadón, 1990; Lavín, Valdés, Gil, & Moral, 1998), where it was induced by the less frequent easterly winds. Only recently, research on this topic has intensified (Fontán, Valencia, Borja, & Goikoetxea, 2008; Llope et al., 2006; Otero & Ruiz-Villarreal, 2008; Prego et al., 2012), showing that summer upwelling was more frequent than traditionally believed (Alvarez et al., 2011; Alvarez, Gomez-Gesteira, deCastro, Gomez-Gesteira, & Dias, 2010). Local upwelling induced by northerly winds can also be observed in summer along the French continental shelf (Puillat et al., 2004).

The continental shelf is about 150 km wide at the northern part of the French coast. Circulation is governed by the combined effect of buoyancy due to the Gironde and Loire rivers, tides, and wind. In addition, cross-shelf transport is enhanced along the axis of submarine canyons (Cap Breton).

5.2.2.4 Mixed Layer Depth

The MLD is the deepest layer affected by turbulent mixing, which marks the width of the upper ocean that interacts with the atmosphere. It plays a key role not only in climate control but also in the biology of marine organisms. The deepest MLDs in the North Atlantic occur in winter and early spring. During spring, the onset of surface heating produces a re-stratification of the upper ocean, giving as a result shallower MLDs.

Several studies have focused on MLD in the Bay of Biscay during the past decade, although most of them are conducted at a local scale. González-Pola, Fernández-Díaz, and Lavín (2007) found that MLD does not surpass the 200 dbar level at the linear section off Santander. Hartman et al. (2014) used data from Argo floats and found a maximum MLD deeper than 450 m during the cold winter of 2009/2010. Somavilla, González-Pola, Ruiz-Villarreal, and Lavín (2011) use data from the same section combined with a one-dimensional water column model (GOTM) to analyze MLD variability. They found that during the 1970s and 1980s the MLD was shallower than from 1995 onward. In addition, Somavilla et al. (2009) studied the consequences of an extreme mixing event that occurred during the winter of 2005 on the hydrographic structure. Costoya, de Castro, and Gómez-Gesteira (2014) and Costoya, DeCastro, Gómez-Gesteira, & Santos, 2014 analyzed winter MLD in most of the Bay of Biscay (except in the shallow part of the French shelf) finding values that range from 140 to 270 m deep.

5.2.2.5 Waves and Tides

Owing to the particular features of the Bay of Biscay, which is a semi-enclosed bay, wave features are similar in most of the area, although slightly modulated by topographic and bathymetric constraints. The main characteristics of waves at different sampling points are shown in Table 5.3.

The most frequent peak periods range from 9 to 12 s at the three sampling points. Maximum significant wave heights higher than 12 m were detected at all locations, being heights higher than 10 m frequent in JFM and ND, which proves that the more severe sea states correspond to autumn and winter.

Clearly, the most frequent direction is from NW that corresponds to the open boundary of the region allowing the eastward propagation of the swell generated in the Atlantic Ocean. The rest of the frequent directions depend on topographic constraints; thus, for example, the probability of waves from W is important at mid-Bay and *Estaca de Bares* but negligible at *Cape Peñas*. Only directions with a frequency higher than 10% were considered in Table 5.3.

Tides in the Bay of Biscay are semidiurnal and tend to increase eastward when the tidal wave propagates over the French shelf. The existence of an anphidromic point in the North Atlantic (approximately at 52°N, 40°W) generates a counterclockwise rotation in the Atlantic forcing tide to propagate from west to east along the Cantabrian coast, and from south to north (at least macroscopically) along the French coast. The most probable amplitudes calculated for the harbors

TABLE 5.3 Main Characteristics of Waves in the Bay of Biscay, Determined Using Data Provided by Puertos del Estado (http://www.puertos.es/)

	Mid-bay	Estaca de Bares	Cape Peñas
Location	5°W 45.25°N	7.67°W 44.12°N	6.16°W 43.75°N
Type of data	Modeled	Buoy	Buoy
Period under study	1958–2016	1996–2016	1996–2016
Most frequent significant wave height (m)	1.5–2.0	1.5–2.0	1.0–1.5
Most frequent peak wave period (s)	9–12	9–12	9–12
Maximum significant wave height (m)	13.3	12.9	12.2
Months with maximum wave heights	JFM,ND	JFM,ND	JFM,ND
Most frequent directions	NW (41%)	NW (43%)	NW (67%)
	W (39%)	W (26%)	N (18%)
		N (14%)	

of Gijon, Santander, and Bilbao using data provided by *Puertos del Estado* over the period 1992–2016 range from 1.4 to 4 m, corresponding to neap and spring tides. Macroscopically, these values are also valid for the French coast, although higher values can be observed at several locations (e.g., La Rochelle and the estuary of the Loire river), where the presence of narrow passages reinforces the tidal wave.

5.3 MAJOR HABITATS AND ECOSYSTEM COMPONENTS

5.3.1 Plankton

Plankton (bacterioplankton, phytoplankton, zooplankton, and ichthyoplankton) are fundamental to life in the ocean. Information on their diversity, abundance, phenology, and production is important for many purposes. Such information has been collected for over 25 years in some parts of the Bay of Biscay through monthly plankton sampling in fixed stations (time series projects) as well as for dedicated mesoscale surveys (mostly carried out in spring and fall). Several research organizations established in the region (e.g., IEO, AZTI, IFREMER, and the Universities of Oviedo and Basque Country) currently collaborate in such surveys, but the desirable comprehensive global coverage has not yet been achieved (Table 5.4.).

5.3.1.1 Bacterioplankton

Bacterioplankton are microscopic in size (sometimes at or below the resolution limit of compound light microscopes) and their importance lies in their abundance and in their wide diversity of metabolic strategies. There is a fundamental problem with defining "species" of bacteria, since the traditional species concept cannot easily be applied to many marine bacteria. The relatively incipient development of robust and accessible molecular techniques is allowing us to know the phylogenetic composition of bacterioplankton, represented mainly in these waters by clades of Alphaproteobacteria (SAR11 and Rhodobacteraceae), Gammaproteobacteria (mainly SAR86), and Flavobacteria (Alonso-Sáez, Díaz-Pérez, & Morán, 2015).

The analysis of more than 10 years (2002–2016) of monthly observations in coastal waters of the southern Bay of Biscay off Gijón reveals the existence of a very consistent seasonal pattern in abundance, size, and biomass of the two most common groups of heterotrophic bacterioplankton based on flow-cytometry and bacteria with high (HNA) and low (LNA) content in nucleic acids. Their bimodal pattern, with abundance (106 cells $\mathrm{mL^{-1}}$), biomass (max. 16–20 $\mu\mathrm{g\,C\,L^{-1}}$), and integrated yield (maximum 93–139 $\mathrm{mg\,C\,m^{2}\,day^{-1}}$) maxima in spring and autumn, match the hydrographic mixing-stratification cycle characteristic of temperate zones, which seems to be controlled by temperature in winter and spring, and by substrate resource in summer-early autumn (Calvo-Díaz, Franco-Vidal, & Morán, 2014).

TABLE 5.4 Snapshot of Ecological Information Available in the Bay of Biscay for the Main Plankton Groups

Ecological Information	Bacterioplankton	Phytoplankton	Zooplankton	Ichthyoplankton	
				Eggs	Larvae
Taxonomy	🟥	🟩	🟩	🟨	🟩
Abundance and biomass	🟩	🟩	🟩	🟩	🟩
Distribution	🟩	🟩	🟩	🟩	🟩
Seasonal variability	🟩	🟨	🟨	🟨	🟨
Spatial variability	🟨	🟨	🟨	🟨	🟨
Interannual variability	🟨	🟨	🟨	🟨	🟨
Life history/ Phenology	🟥	🟥	🟥	🟨	🟩
Productivity	🟥	🟥	🟥	🟥	🟥

Color categories stands for: *green*, "relatively good information"; *yellow*, "limited information (some aspects or information from some regions or seasons unknown)", and *red*, "poor information and data availability."

Cyanobacteria such as Synechococcus are important organisms in the Bay of Biscay, although little is known about their distribution and genetic variability. Some species of Synechococcus and Trichodesmium have the ability to fix nitrogen gas (N_2), so they are important contributors to the geochemical budgets in marine ecosystems. Bacteria are important in cycling carbon and nutrients in the ocean and as the source of long food webs; however, our current understanding of functional variables such as nitrogen fixation, carbon cycling, and other biogeochemical processes, as well as net production and biomass transfer to the trophic web, is limited. Although much longer time series are needed to ascertain the effect of increasing temperature in ocean waters, Morán et al. (2015) observed a trend of decreasing cell size when increasing temperature, especially in LNA bacteria (less diverse and dominated mainly by members of the clade SAR11).

5.3.1.2 Phytoplankton

Phytoplankton are also at the base of the marine food web. During winter, in temperate areas such as the Bay of Biscay, there is not enough sunlight to sustain plankton growth and net production because the winds over the ocean cause deep mixing of water that takes phytoplankton cells away from the light (Varela, 1996). Owing to their pigments (e.g., chlorophyll), the color of the ocean changes in relation to their varying abundance, and since 1978, it has been possible to estimate the amount of chlorophyll at the ocean surface with ocean-color sensing satellites as well as visualize the spatial dimensions and dynamics of the seasonal blooms (Fig. 5.3.), although we are still unable to identify the species composition of blooms that are detected by remote sensing.

Other gaps that limit our understanding of phytoplankton ecology (Table 5.4.) include the few and/or poor-quality productivity estimates, the seasonal, spatial, and interannual variability (except in selected regions); what controls species composition within phytoplankton blooms (especially harmful algal blooms); or which species can reach very high abundance while others remain at barely detectable levels.

The SW part of the Bay of Biscay (the area around Galicia) is the most productive (annual averages of 43.44 $\mathrm{mg\,Chla\,m^{-2}}$ and 138.07 $\mathrm{mg\,C\,m^{-2}\,day^{-1}}$) because it is influenced by the Galicia upwelling system (Bode et al., 2012; Bode, Alvarez-Ossorio, Cabanas, Miranda, & Varela, 2009; Bode, Hare, Li, Morán, & Valdés, 2011), which extends toward the East and with seasonal strong signals close to the main Capes (e.g., Cape Peñas in Asturias with annual averages of 30.65 $\mathrm{mg\,Chla\,m^{-2}}$ and 82.84 $\mathrm{mg\,C\,m^{-2}\,day^{-1}}$). Also, the French waters in the northern part of the Bay of Biscay, and the areas in the vicinity of river discharges show levels of chlorophyll higher than in the rest of the Bay. The mid and inner parts of the Bay are less

FIG. 5.3 A huge phytoplankton bloom in the Bay of Biscay (most likely Coccolithophores). *Source: MODIS image acquired by NASA May 20, 2010 at 10:35 UTC.*

productive. Diatoms tend to dominate the species composition in the Bay of Biscay forming the bulk of the phytoplankton biomass, particularly in the upwelling areas (Morán & Scharek, 2015).

Phytoplankton species composition in the Bay of Biscay vary seasonally and among regions, with the spring bloom mostly composed of diatoms, which are replaced by dinoflagellates during the summer, once the thermocline develops (Casas, Varela, & Bode, 1999; Varela, Prego, Belzunce, & Martín Salas, 2001). For both diatoms and dinoflagellates, we have good taxonomic knowledge and species of Thalassiosira, Chaetoceros, Nitzschia, Coscinodiscus, Peridinium, and Ceratium are quite common. However, for other smaller groups within the Picophytoplankton (less than 2 μm) and the Nanophytoplankton (2–20 μm), our knowledge is still limited and also their genetic variability, nutrient requirements, and roles in marine ecosystems are not well known.

Coccolithophores deserve special mention as they are important organisms in biogeochemical cycles and abundant in the open waters of the Bay of Biscay. Their blooms caused significant changes to food web dynamics moving huge amounts of carbon from the surface waters to deep layers or to the bottom and therefore sequestering carbon to the seabed sediments where it persists for decades or hundreds of years, therefore mitigating the effects of global warming. In spite of its importance, limited information is available on the distribution, production, and factors initiating blooms of coccolithophores (Fig. 5.3.).

Analysis of monthly phytoplankton data over 20 years in the North Iberian Peninsula shows that there is not a uniform response to climate change, whereas data in the central Cantabrian Sea indicate a warming effect; this signal is unclear in Galicia (Bode et al., 2009; Varela et al., 2012).

5.3.1.3 Zooplankton

Zooplankton provide the food web link between phytoplankton and larger animals (fishes, whales, and seabirds). They are often categorized by size as microzooplankton (20–200 μm), mesozooplankton (0.2–20 mm), and macrozooplankton (2–20 cm). Most zooplankton species are herbivorous, although there are also numerous carnivorous taxa. The taxonomy of zooplankton in the Bay of Biscay is well known for copepoda and cladocera. However, the inability to survey zooplankton quickly and remotely, and the time consumed for the samples identification strongly limit our ability to study the spatial and temporal variability, phenology, and production with the required resolution, which means that "function-related" information on zooplankton is quite limited (Table 5.4.).

Of the 30 or so groups which form the zooplanktonic community, the most important in specific richness, persistence, abundance, and ecological significance is that of copepods. In the Bay of Biscay, 95 species were identified, and copepods made up 71%–81% of the total abundance of zooplankton (Albaina & Irigoien, 2007; Alvarez-Marqués, 1980; Valdés, 1993). Despite this specific richness, only a few species characterize this region in terms of abundance and persistence and account for 90% of the total abundance of copepods (Valdés et al., 2007). These dominant species are *Acartia clausi*, *Paracalanus parvus*, *Temora longicornis*, *Pseudocalanus elongatus*, *Calanus helgolandicus*, *Centropages typicus*, *Oncaea media*, *Oithona* spp., and *Clausocalanus* spp. (Albaina & Irigoien, 2007; Valdés et al., 2007). The remaining biomass includes Cladocera, Siphonophora Chordata, and Chaetognatha. A conspicuous feature of the zooplankton in recent years has been the presence of *Temora stylifera*, a southern copepod species (Valdés et al., 2007; Villate, Moral, & Valencia, 1997) which is now common in our waters and likely related to the ocean warming experienced in the past decades (Fig. 5.4.).

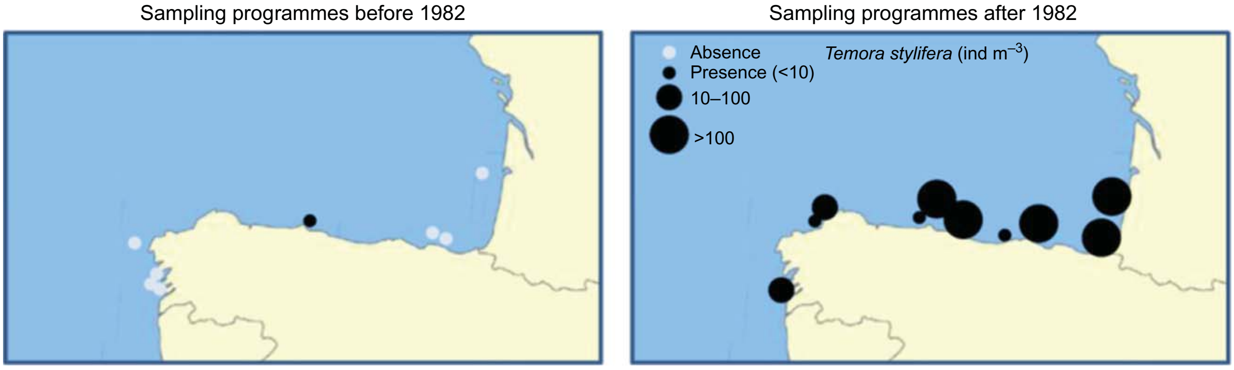

FIG. 5.4 Records of *Temora stylifera* in studies before and after 1982 (i.e., 1967–1982 and 1982–2004). *After Valdés, L., Lopez-Urrutia, A., Cabal, J., Alvarez-Ossorio, M., Bode, A., Miranda, A., Cabanas, M., Huskin, I., Anadón, R., Alvarez-Marqués, F., Llope, M., Rodriguez, N. (2007). A decade of sampling in the Bay of Biscay: What are the zooplankton time series telling us? Progress in Oceanography 74(2–3), 98–114.*

The zooplankton assemblage of the shelf region also contains many species of invertebrate larval stages and fish eggs and larvae that are planktonic for at least part of their lives (meroplankton). The zooplankton in open waters of the Bay are dominated by large species such as: *Calanus gracilis*, *Eucalanus elongatus*, *Candacia armata*, *Euchaeta hebes*, and *Metridia lucens*. The most abundant euphausiids are *Nyctiphanes cochii* and *Meganyctiphanes norvegica*. Gelatinous plankton are also important in the Bay of Biscay with regular seasonal peaks of Siphonophora (mostly in spring) and large blooms of Salpidae which occur from time to time.

The annual cycle of abundances and biomasses of zooplankton in the Bay of Biscay shows two annual peaks, in spring and autumn, corresponding to, but lagging with, the pulses of phytoplankton production (Valdés, 1993; Valdés et al., 2007). In coastal zones, mesozooplankton abundance presents a seasonal variation with absolute values rarely surpassing 3000 ind m^{-3} in spring, and winter is well defined with values of around 250 ind m^{-3}. The oceanic area of the Bay presents a pattern of oligotrophic regions with slight variations in values of abundance and biomass throughout the annual cycle and a single period which generally coincides in April, when communities develop and reach annual peaks (Valdés & Moral, 1998).

Structural variables such as abundance and biomass are closely related to processes occurring at a mesoscale level (e.g., river plumes, local upwelling) and also determined by the warming and strength of the stratification of the water column in summer, showing a decreasing gradient of biomass from Galicia to the inner parts of the Bay of Biscay (Valdés et al., 2007). In the coast–ocean axis, the gradient in biomass is marked and persistent and it is enhanced by the higher abundance of meroplankton in shallower waters (Valdés, 1993). Vertical distribution of zooplankton by length classes has been studied in the southern Bay of Biscay by Fernández de Puelles, Valdés, Varela, Alvarez-Ossorio, and Halliday (1996). These authors observed spatial segregation related to the ontogeny of species such that copepod eggs appeared aggregated at the depth at which the adults were found, and successive stages of copepodites appeared in neighboring water layers.

Global change is predicted to increase the degree and duration of the stratification phase (Roemmich & McGowan, 1995; Sarmiento et al., 2004). As the stratification reaches deeper waters and the nutrient depletion in photic layers is extended in time, consequences are expected in seasonal and annual phytoplankton dynamics resulting in increased oligotrophy. We hypothesize that the inner Bay of Biscay will be less productive in the future. Valdés et al. (2007) reported a decrease in primary production in the vicinities of Cudillero (Southern Bay of Biscay) and also the effect of increased stratification in the reduction of zooplankton biomass. These changes in functional (primary production) and structural (biomass) variables are also consistent with the appearance of thermophilic and opportunistic species, such as *T. stylifera* and *Ditrichocorycaeus anglicus*, in the past decades in the Bay of Biscay.

5.3.1.4 Ichthyoplankton

Ichthyoplankton are the eggs and larvae of fish and form part of the plankton assemblages during their development. Ichthyoplankton samples can reflect the spawning areas of commercial species and their abundance tell us about the relative population size for the spawning stock. Also, the abundance of successive developmental stages tells us about survival rates, which can be used to provide indexes of future fish recruitment. Many research projects and dedicated surveys were carried out in the Bay of Biscay during the past 3 decades to study the abundance and distribution of fish larvae. Also, different experiments have provided information on different aspects of eggs and larval physiology and life history. However, most of the above-mentioned surveys were carried out in spring (during the spawning season of most important fish commercial species), and therefore we still have limited information about spatial and temporal variability of the ichthyoplankton from some regions and seasons (Table 5.4.).

Species composition, abundance, and distribution of fish larvae in the Bay of Biscay are relatively well known. Fish larvae from 99 species, belonging to 37 families, were identified in the region. Families with a higher number of species were Gadidae, Sparidae, and Labridae. According to Rodriguez (2008), the larval fish assemblage in the central Cantabrian Sea was dominated by pelagic fish species, with *Sardina pilchardus* as the most abundant all the year round but with peaks in winter and spring. Mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*) are highly seasonal with peaks in spring. Blue whiting (*Micromesistius poutassou*) and anchovy (*Engraulis encrasicholus*) are also abundant in summer and fall, respectively. Sardine and anchovy eggs accounted for 31.7% of the abundance of fish eggs (Rodriguez, 2008).

Sardine and anchovy spawn in shelf waters, whereas mackerel, horse mackerel, and hake are a slope spawning species (Fig. 5.5.; Valdés et al., 1996). The data analyzed by Bernal et al. (2007) and Rodriguez (2008) show the central Cantabrian Sea shelf as the most important for sardine spawning during spring, along the NW and North coasts of the Iberian Peninsula, whereas Motos, Uriarte, and Valencia (1996) found that anchovy larvae have their main hot spots in the Basque country and the French continental shelf, where river discharges are important.

Regarding vertical distribution, fish larvae concentrate in the upper layers of the water column (Coombs, Morgans, & Halliday, 2001; Rodriguez et al., 2015; Rodriguez, Gonzalez-Pola, Lopez-Urrutia, & Nogueira, 2011). For instance,

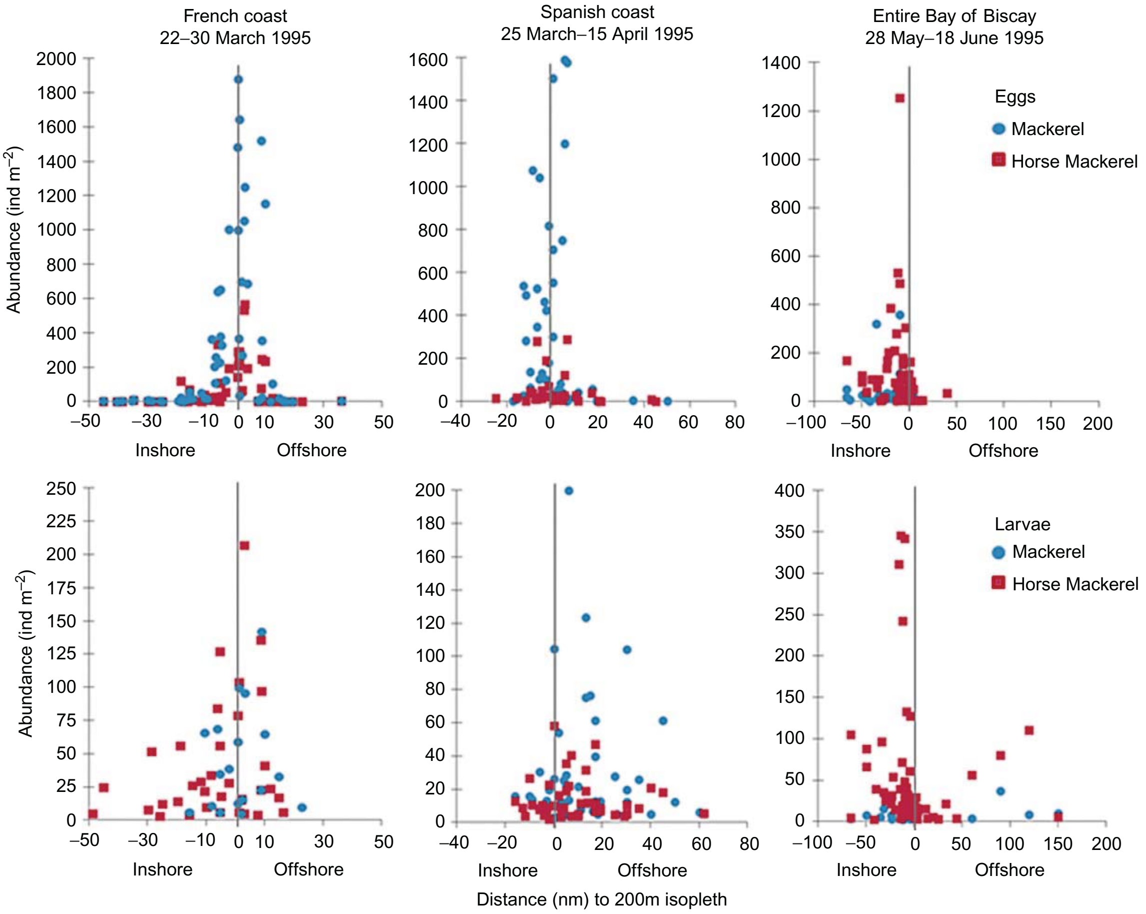

FIG. 5.5 Eggs and larvae abundance scatterplots for mackerel and horse mackerel versus the 200 m isopleth (shelf break). *Modified from Valdés, L., Lago de Lanzós, A., Solá, A., Franco, C., Sanchez, P., Alvarez, P. (1996). Hake, mackerel and horse mackerel distribution of eggs and larvae in relation to geostrophic circulation in the Bay of Biscay. ICES CM 16, 15.*

Rodriguez et al. (2015) found that 92% of the catches in February/March in waters around Galicia were made in the upper 100 m and only 8% were captured in deeper waters. The larger-sized larvae collected at night in the upper layers suggest net avoidance by these larvae during the daytime, but it could also be a signal of daily vertical migrations.

Cultured larvae and eggs of different species have been used for experimental studies. For example, Guevara-Fletcher, Alvarez, Sanchez, and Iglesias (2017) tested the effect of temperature on the development of newly hatched larvae (yolk-sac larvae) of *Merluccius merluccius* (European hake) from Galicia (adults captured in surrounded waters and maintained in captivity) and have found the thermal limit for egg development in 22°C and reaching a metabolic optimum at 10.5°C (when the larvae reach a maximum length of 4.3 mm). On the other hand, Guisande, Riveiro, Sola, and Valdés (1998) tested the effects of biotic and abiotic factors on the biochemical composition of wild eggs and larvae of several fish species (mackerel, horse mackerel, sardine, and anchovy) and found a mechanism to achieve optimal larval buoyancy which consists in the trade-off between protein and lipid production; for example, more lipid percentage and a reduction of larval protein percentage were observed as temperature increased and salinity decreased, which is an interesting physiological characteristic to be considered in a scenario of a warmer ocean.

5.3.2 Benthos

A first map of benthic habitats within the Bay of Biscay was built by Galparsoro, Borja, and Uyarra (2014) and Vasquez et al. (2015), based upon data from EMODnet—European Marine Observation and Data Network (www.emodnet-hydrography.eu), EUSeaMap—Mapping European seabed habitats (http://jncc.defra.gov.uk/page-6266), and MeshAtlantic project (www.meshatlantic.eu). The Bay of Biscay accounts for 42 out of the 62 habitats identified in the NE Atlantic, but most of the habitats were classified to levels 3–4 of the EUNIS (European Union Nature Information System) system, and

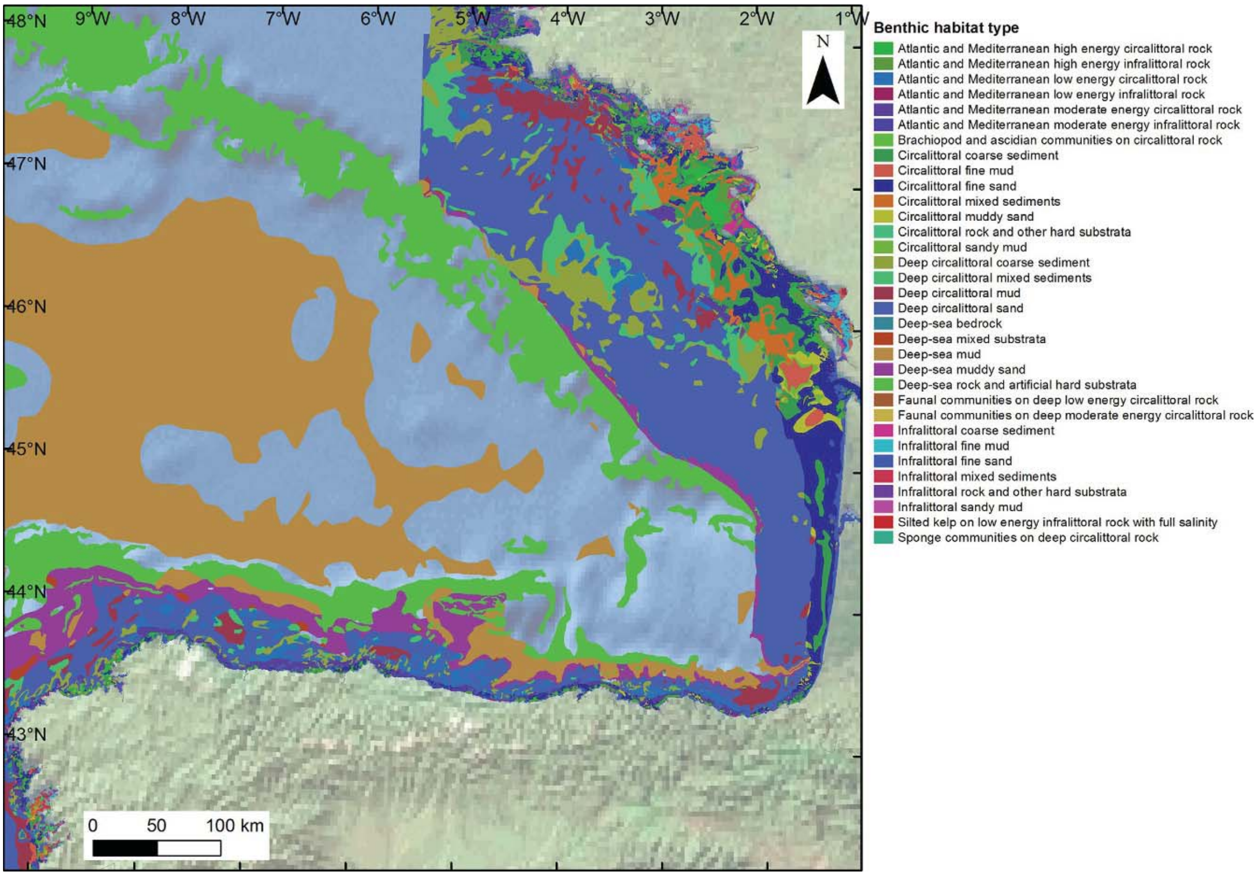

FIG. 5.6 Mosaic of EUNIS seabed habitat classes for the Bay of Biscay. *Modified from Galparsoro, I., Borja, A., Uyarra, M.C. (2014). Mapping ecosystem services provided by benthic habitats in the European North Atlantic Ocean. Frontiers in Marine Science 1, doi: 10.3389/fmars.2014.00023 and Tempera, F. (2015). Bringing together harmonized EUNIS seabed habitat geospatial information for the European Seas. Joint Research Center, Report EUR 27237 EN, 20 p.*

were restricted to the continental shelf. Recently, Tempera (2015) completed a seabed habitat map of the whole of Europe, including abyssal habitats. As such, the Bay of Biscay habitats map was completed, although the level of resolution in EUNIS ranges from levels 2–4 within the area (Fig. 5.6.).

In turn, data on benthic communities for the complete Bay are not available, being absent in the pan-European MacroBen database (Vanden Berghe et al., 2009). However, there are some descriptions in several parts of the continental shelf of the Bay of Biscay, such as in the northern part of the Bay in France (Hily, Le Loc'h, Grall, & Glémarec, 2008) or the Basque Country (Borja et al., 2004) and some examples in the bathyal–abyssal habitats, such as in Avilés Canyon (Louzao et al., 2010), in Cap-Breton Canyon (Elizalde, Sorbe, & Dauvin, 1993), or in the middle of the Bay (Laubier & Sibuet, 1979). For megafauna and epifauna, there are extensive studies, sometimes linked to fishing trawls, such as in the French (Brind'Amour et al., 2014) and Spanish (Serrano, Sánchez, & García-Castrillo, 2006) continental shelves and canyons in northern Spain (Serrano, Sánchez, Punzón, Velasco, & Olaso, 2011). One feature of the benthic communities is that they have species characteristic of cold waters (i.e., Laminariaceae) in the extremes (Galicia, because of the upwelling, and Brittany, because of latitude), and warm water species (mainly red algae) in the Basque Country, with many Mediterranean species (Alcock, 2003), because of the warmer summer temperatures in the south-eastern part of the Bay, as shown in Table 5.1.

The information provided by the above authors is difficult to compare, since the richness and abundance/density values provided vary depending on the sampling method and the presentation of data (Table 5.5.). However, for megafauna-epifauna in the continental shelf, the richness ranges between 20 and 62 species, with abundances between 75 and 5954 ind Ha^{-1} and diversity of 0.59–3.91 bit ind^{-1}; in turn, canyons and slope present much lower structural parameter values. For the continental shelf, infauna richness ranges between 7 and 134, abundance between 150 and 2000 ind m^{-2}, and diversity between 1.94 and 6 bits ind^{-1}. Values range between 28 and 143 species in slope and bathyal areas, and between 505 and 2008 ind m^{-2} in the abyssal plain.

TABLE 5.5 Some Structural Parameters of Benthic Communities Within the Bay of Biscay, for Infauna and Megafauna-Epifauna

Studied Areas and Type of Fauna	Richness (Number Species)	Abundance	Shannon's Diversity (bit ind^{-1})
Megafauna-Epifauna			
Spanish continental shelf (1)		(ind Ha^{-1})	
41–100 m	28.0–62.5	75.4–4723.6	0.59–3.06
138–188 m	32.5–55.0	81.6–382.6	3.24–3.79
291–354 m	25.0–42.5	150.5–5953.9	1.99–3.91
North French continental shelf (2)			
30–600 m	19.50 (mean)		
South French continental shelf (7)		(ind 100 m^{-3})	
91 m	53 (mean)	3616 (mean)	3.70 (mean)
126 m	59 (mean)	5856 (mean)	2.70 (mean)
179 m	53 (mean)	4253 (mean)	3.30 (mean)
Spanish canyons/slope (3)		(ind Ha^{-1})	
400–750 m	13.0–17.0 (mean)	50.0–280.0 (mean)	1.8–2.4 (mean)
French slope/canyons/bathyal (7)		(ind 100 m^{-3})	
425 m	58 (mean)	2726 (mean)	2.62 (mean)
714 m	86 (mean)	4461 (mean)	3.47 (mean)
1024 m	98 (mean)	604 (mean)	5.75 (mean)
Infauna			
Spanish (Basque) continental shelf (4)		(ind m^{-2})	
20–40 m	32	200	3.8
60–100 m	22–42	150–500	3–4
70–150 m	80–130	900–2000	5–5.7
150–250 m	75–120	500–1000	5.4–6
Spanish (Asturias) continental shelf (6)			
31–300 m	29–89		
117–307 m	52–134		
North French continental shelf (5)		(ind grab^{-1})	
0–80 m	17–63	20–98.5	1.94–3.93
80–120 m	14–71	14.4–78.9	1.98–3.66
120–200 m	7–36	5.5–241	3.06–3.22
Spanish slope/canyons/bathyal (6)			
468–790 m	28–64		
198–1100 m	57–143		
720–1400 m	37–94		

Continued

TABLE 5.5 Some Structural Parameters of Benthic Communities Within the Bay of Biscay, for Infauna and Megafauna-Epifauna—cont'd

Studied Areas and Type of Fauna	Richness (Number Species)	Abundance	Shannon's Diversity (bit ind^{-1})
Middle of the Bay-abyssal part (8)		(ind m^{-2})	
2000–3000 m		995–2008	
4200–4700 m		505–919	

(1) Serrano et al. (2006), (2) Brind'Amour et al. (2014), (3) Serrano et al. (2011), (4) Borja et al. (2004), (5) Hily et al. (2008), (6) Louzao et al. (2010), (7) Elizalde et al. (1993), and (8) Laubier and Sibuet (1979).

Some of these values in the continental shelf (e.g., richness) are higher than those found in the English Channel or the North Sea (Brind'Amour et al., 2014); in turn, abyssal infaunal abundance is only slightly higher than that in Norway (Laubier & Sibuet, 1979).

5.3.3 Fishes

Fisheries in the Bay of Biscay and the Iberian Coast are managed under the European Common Fisheries Policy (CFP), with some fisheries managed by the North-East Atlantic Fisheries Commission (NEAFC) and by coastal states. Responsibility for salmon fishery management lies with the North Atlantic Salmon Conservation Organization (NASCO) and for large pelagic fish with the International Commission for the Conservation of Atlantic Tunas (ICCAT). Fisheries advice is provided by the International Council for the Exploration of the Sea (ICES), the European Commission's Scientific Technical and Economic Committee for Fisheries (STECF), and the South Western Waters Advisory Council (SWWAC).

Both demersal and pelagic commercial fisheries occur in most parts of the Bay of Biscay and many fish stocks were overexploited in past decades. A general decrease of fishing effort in the Bay of Biscay has contributed to an overall decline in the fishing mortality of commercial fish stocks. In the early 1990s, the decrease was based on policy measures aimed at the reduction of the fishing fleet; since 2002, the CFP reforms and after the introduction of vessel monitoring systems (the VMS technology provides geo-referenced data of fishing boats), the fishing mortality declined close to the level that produces maximum sustainable yield; as a consequence, an increase in the mean spawning-stock biomass of most regulated stocks have been observed since then (ICES, 2016).

Some stocks (i.e., anglerfish *Lophius* spp. and anchovy) are now fished at or below maximum sustainable yield, fishing mortality targets, or with spawning-stock biomass above reference points; some others are still above target (i.e., hake *Merluccius merluccius* and megrim *Lepidorhombus* spp.). Stocks of small pelagics like sardine and anchovy are highly influenced by natural recruitment variability and are therefore prone to periodic collapses linked to oceanographic variability. These stocks are closely monitored and regulated by strict management (ICES, 2016).

Nearly 700 fish species are found in the region. In terms of biogeography, many species reach the southern or northern limits of their distribution ranges in the Bay of Biscay (Quéro, Dardignac, & Vayne, 1989; Sánchez, 1993). The boundary for the cold temperate species can be represented by the latitude of 47°N being the warm temperate species mainly found in the south of the Gironde estuary. Submarine canyons and seamounts (such as el Cachucho/Le Danois) are classified as hot spots for biodiversity.

The pelagic habitat is mainly dominated by sardine, anchovy, mackerel, horse mackerel, and blue whiting (*Micromesistius poutassou*). Some migratory species also appear in specific periods, such as tuna species (albacore *Thunnus alalunga* and bluefin *Thunnus thynnus*), which feed upon smaller pelagic fish.

The anchovy is the only pelagic species whose principal population is confined to the Bay of Biscay. The distribution of sardine, mackerel, and horse mackerel extends outside from the bay, both to the north (Brest) and the south (Galicia). Mackerel and horse mackerel are highly migratory species, and especially striking long-distance migrations have been recorded on the northern coasts of Europe (Lockwood, 1988). In the case of mackerel, adults throughout the southern Bay of Biscay join the general migration of their species in the northeast Atlantic during the second half of the year, reaching the coast of Norway (Uriarte et al., 2001).

Among the demersal species which live at a great range of depths, those belonging to the upper trophic levels are the most important: hake, monkfish, conger eel, cod, etc. Hake is the most abundant predator species in the demersal community. Anglerfish, megrim, and sole are more abundant in the northern part of the Bay of Biscay. Gregarious and very abundant species, such as blue whiting, silvery pout, Norway pout, and boarfish, which serve as food for other species, present the stenobathyal distribution. Skates, sharks, and deep-sea fish occur over the continental slope and in the deeper parts of this region (Lorance, Latrouite, & Seret, 2000).

Whereas the fish species composition and distribution and the reproductive biology and growth parameters related to management purposes were largely studied during the 1980s and 1990s, in the past 2 decades fish research projects have shifted toward more ecological and comprehensive investigations, for example: trophic relationships, ecological models, impacts of fishing in the ecosystem, and climate change. Hence, the Bay of Biscay shelf edge is a major area of spawning for wide geographical area distribution species, like blue whiting, mackerel, horse mackerel, and hake; the species assemblages and their habitats (Massé, 1996; Poulard, Blanchard, Boucher, & Souissi, 2003; Sánchez & Serrano, 2003; Souissi et al., 2001). Also, it is a key area in the migration routes of adult mackerel (Uriarte et al., 2001). Non-indigenous species are entering the Bay and some already have established permanent populations (Quéro, Du Buit, & Vayne, 1998). We now know the ecological conditions favoring anchovy spawning and recruitment (Irigoien et al., 2009; Motos, 1994).

Regarding anthropogenic pressures, the effect of fishing on marine ecosystems is probably the most widespread in the Bay of Biscay, which is sometimes reinforced by ocean warming (although it is not easy to disentangle the effect of both stressors). As a result of different research programse, it was shown that the mean trophic level of the demersal fisheries on the Cantabrian Sea shelf from 1983 to 1999 declined from 4.1 to 3.7 (Sánchez & Olaso, 2004); that the distribution patterns of demersal species is highly determined by hydrographic features (e.g., poleward current, upwelling events, river plumes) but also by spatial structures (e.g., canyons, seamounts) (Sanchez, Gil, Sanchez, Mahe, & Moguedet, 2001). There is also evidence that climate change is affecting the fish community structure (Chust et al., 2011), and that species of flat fish such as plaice and dab are sensitive to oceanic winter warming (Désaunay, Guérault, Le Pape, & Poulard, 2006; Poulard & Blanchard, 2005). Although the analysis of different results show that the Bay of Biscay is under a meridionalization process, it is necessary to work longer time series and develop more studies before the changes forced by climate change could be included in ecosystem based management plans (Goñi et al., 2014; Punzón et al., 2016).

5.3.4 Seabirds

Populations of seabirds are strongly associated with fish and benthic invertebrate distributions; they represent an important part of their diet. Many species of fish find their distribution limits (Northern or Southern) in the Bay of Biscay (Castro et al., 2006), which determines the species of seabirds that can be found as well as their distribution and abundance. Species such as *Hydrobates pelagicus* (European storm petrel), *Phalacrocorax aristotelis* (European shag), *Larus argentatus* (herring gull), *L. atricilla* (laughing gull), *L. michahellis* (yellow-legged gull), *L. fuscus* (lesser black-backed gull), *Rissa tridactyla* (black-legged kittiwake), and *Uria aalge* (common guillemot) visit the Bay of Biscay for feeding and nesting during their breeding period (ICES, 2016; Lorance, Bertrand, Brind'Amour, Rochet, & Trenkel, 2009). Other species, like *Morus bassanus* (northern gannet), and several shearwater species (e.g., *Puffinus mauretanicus* (Balearic shearwater), *Calonectris diomedea* (Cory´s shearwater), and *P. puffinus* (Manx shearwater)), use the southern part of the Bay of Biscay as a passage for their migrating route from their north Atlantic breeding grounds to the wintering areas in the Bay of Biscay or further south (Castro et al., 2006).

In terms of abundance, *M. bassanus*, *Larus spp*. (seven species of gulls), *P. mauretanicus*, *P. puffinus*, *P. griseus* (sooty shearwater), *Calonectris diomedea*, *Alca torda* (razorbill), and *Fratercula arctica* (Atlantic puffin) are among the most abundant species. Other species, such as the *Uria aalge* and *Rissa tridactyla*, have nearly disappeared in this area (ICES, 2016; Lorance et al., 2009). From all the species present in the Bay of Biscay, only *P. mauretanicus* is classified as threatened by the IUCN. However, this area is neither its main nor essential habitat, nor where the threat is posed (Lorance et al., 2009). In fact, threats posed to seabirds in the Bay of Biscay mainly relate to oil spills, bycatch in fisheries, and climate change. Negative impacts on seabirds (and benthic species on which their diets depend) associated with oil pollution have been reported by Cadiou et al. (2004) and Castege et al. (2004, 2007); Castège, Milon, and Pautrizel (2014), after the Erika and Prestige oil spills. On the other hand, although bycatch is happening and seriously impacting some species of marine mammals, its impact on seabirds is less clear (Lassalle et al., 2012). Finally, Hemery et al. (2008) reveal that communities of seabirds are changing from cold-water to warm-water species as a result of climate change.

Despite these existing threats to seabird populations in the Bay of Biscay, this area does not seem to be one where significant impacts are observed. Nevertheless, seabird research is rather limited, and further efforts to gain better knowledge on existing populations and effects of bycatch are needed (ICES, 2008).

5.3.5 Mammals

Several organizations and platforms (e.g., ORCA www.orcaweb.org.uk, SeaWatch Foundation www.seawatchfoundation.org.uk, Marine Life www.marine-life.org.uk, Centre de la Mer Biarritz www.centredelamer.fr, ALNILAM www.alnilam.com.es, AMBAR www.ambarelkartea.org, CEMMA www.cemma.org, CEPESMA www.cepesma.org, European Cetacean Monitoring Coalition www.ecmcweb.org/portal, etc.), in collaboration with ferry companies and research institutions, monitor the Bay of Biscay for marine mammals.

From the information provided by these organizations and four publications specific to marine mammals in the Bay of Biscay (Castro et al., 2006; Lorance et al., 2009; Gibson, 2006; Marine Life, 2016), 42 species have been reported from this ecoregion, representing 35% of the total species of marine mammals worldwide (Jefferson, Leatherwood, & Webber, 1993) (Table 5.6.). However, most of these species are only vagrant or rare visitors in the area, and only seven are considered as common on different publications (Lorance et al., 2009; Marine Life 2016). The major discrepancy between publications relates to the occurrence of Sperm whale (*Physeter macrocephalus*), which is reported as common by Lorance et al. (2009) and as scarce by Marine Life (2016). Furthermore, the Grey seal (considered as common) is not listed either by Gibson (2006) or Marine Life (2016), since these studies only focus on cetaceans (dolphins and whales).

TABLE 5.6 List of Marine Mammal Species Sighted and Reported for the Bay of Biscay as Present or Vagrant

Species	Species	Occurrence				IUCN Categories		
Scientific Name	**Common Name**	**(1)**	**(2)**	**(3)**	**(4)**	**1996**	**2008**	**2016**
Order Cetacea								
Suborder Mysticeti								
Family Balaenidae								
Eubalaena glacialis	North Atlantic right whale			29	Vagrant or ER		EN	EN
Balaena mysticetus	Bowhead whale					LR/cd	LC	LC
Family Balaenopteridae								
Balaenoptera musculus	Blue whale		?	19	Very rare	EN	EN	EN
Balaenoptera physalus	Fin whale	x	Common	5	Common	EN	EN	EN
Balaenoptera borealis	Sei whale		?	12	Regular	EN	EN	EN
Balaenoptera brydei	Bryde's whale				Vagrant or ER		DD	DD
Balaenoptera acutorostrata	Common Minke whale	x	?	8	Regular	LR/nt	LC	LC
Megaptera novaeangliae	Humpback whale	x	Rare	17	Very rare	VU	LC	LC
Suborder Odontoceti								
Family Physeteridae								
Physeter macrocephalus	Sperm whale	x	Common	11	Scarce	VU	VU	VU
Family Kogiidae								
Kogia breviceps	Pygmy sperm whale	x	Rare	24	Vagrant or ER	LR/lc	DD	DD
Kogia simus	Dwarf sperm whale		Vagrant		Stranded	LR/lc	DD	DD

TABLE 5.6 List of Marine Mammal Species Sighted and Reported for the Bay of Biscay as Present or Vagrant—cont'd

Species	Species	Occurrence				IUCN Categories		
Scientific Name	Common Name	(1)	(2)	(3)	(4)	1996	2008	2016
Family Monodontidae								
Monodon monoceros	Narwhal		Vagrant/ Absent			DD	NT	NT
Delphinapterus leucas	Beluga		Vagrant/ Absent			VU	NT	NT
Family Ziphiidae								
Ziphius cavirostris	Cuvier's beaked whale	*x*	Common	7	Common	DD	LC	LC
Hyperoodon ampullatus	N Atlantic bottlenose whale	*x*	Rare	14	Scarce	LR/cd	LC	DD
Mesoplodon densirostris	Blainville's beaked whale		Vagrant/ Absent	28		DD	DD	DD
Mesoplodon bidens	Sowerby's beaked whale		Rare	18	Scarce	DD	DD	DD
Mesoplodon europaeus	Gervais' beaked whale			21	Stranded	DD	DD	DD
Mesoplodon mirus	True's beaked whale		Rare	20	Vagrant or ER	DD	DD	DD
Family Delphinidae								
Orcinus orca	Killer whale	*x*	Rare	13	Very rare	LR/cd	DD	DD
Globicephala melas	Long-finned pilot whale	*x*	Common	4	Regular	LR/lc	DD	DD
Globicephala macrorhynchus	Short-finned pilot whale		Vagrant	22	Stranded	LR/cd	DD	DD
Pseudorca crassidens	False killer whale		Rare	10	Very rare	LR/lc	DD	DD
Feresa attenuata	Pygmy killer whale			16	Very rare	LR/lc	DD	DD
Peponocephala electra	Melon-headed whale			25	Vagrant or ER	LR/lc	LC	LC
Lagenorhynchus albirostris	White-beaked dolphin		Rare	23	Vagrant or ER	LR/lc	LC	LC
Lagenorhynchus acutus	Atlantic white-sided dolphin	*x*	Rare	15	Vagrant or ER	LR/lc	LC	LC
Grampus griseus	Risso's dolphin	*x*	Rare	9	Scarce	DD	LC	LC
Tursiops truncatus	Bottlenose dolphin	*x*	Common	3	Regular	DD	LC	LC
Stenella frontalis	Atlantic spotted dolphin	*x*	Vagrant/ Absent			DD	DD	DD

Continued

TABLE 5.6 List of Marine Mammal Species Sighted and Reported for the Bay of Biscay as Present or Vagrant—cont'd

Species	Species	Occurrence				IUCN Categories		
Scientific Name	**Common Name**	**(1)**	**(2)**	**(3)**	**(4)**	**1996**	**2008**	**2016**
Stenella coeruleoalba	Stripped dolphin	*x*	Common	2	Common	LR/cd	LC	LC
Delphinus delphis	Common dolphin	*x*	Common	1	Abundant	LR/lc	LC	LC
Lagenodelphis hosei	Frasers dolphin			27		DD	LC	LC
Family Phocoenidae								
Phocoena phocoena	Harbor porpoise	*x*	Common	6	Regular	VU	LC	LC
Order Carnivora								
Suborder Pinnipedia								
Family Odobenidae								
Odobenus rosmarus	Walrus	*x*	Vagrant			LR/lc	DD	VU
Family Phocidae								
Phoca vitulina	Harbour seal	*x*	Rare			LR/lc	LC	LC
Phoca hispida	Ringed seal		Vagrant			LR/lc	LC	LC
Pagophilus groenlandicus	Harp seal		Vagrant			LR/lc	LC	LC
Halichoerus grypus	Grey seal	*x*	Common			LR/lc	LC	LC
Cystophora cristata	Hooded seal	*x*	Vagrant			LR/lc	VU	VU

Indication of type of occurrence is indicated when information existed. IUCN category classification at different years (*EN*, endangered; *VU*, vulnerable; *NT*, near threatened; *LC*, least concern; *DD*, data deficient; *LR*, lower risk; *CD*, conservation dependent), with indication of change indicated with color (*red*: degradation, *yellow*: no change; *green*: improvement). Note: ER: extreme rarity. Data from (1) Castro et al. (2006); (2) Lorance et al. (2009); (3) Gibson (2006); and (4) Marine Life (2016).

The main human pressures currently affecting the marine mammal populations in the Bay of Biscay relate to fishing (or ghost fishing) (Lorance et al., 2009). Bycatch and entanglement with lost fishing gear results in mortality. In addition, climate change and collision with vessels affect some of the species visiting the area. Indeed, Hemery et al. (2008) indicate variations in abundance of some of the marine mammal populations for the 1974–2000 period, observing that species with affinities for warmer waters increased populations (e.g., Common dolphin (*Delphinus delphis*)) while the opposite has been observed for species with a preference for colder waters (e.g., Killer whale (*Orcinus orca*)). These threats (together with past overhunting) have put four of the listed species into endangered status. It is important to note that the Fin whale (*Balaenoptera physalus*), cataloged as being endangered, is common in this area, highlighting the importance of this area for this species. Furthermore, the status of 15 of the species is not yet assessed due to data deficiency.

5.4 POPULATIONS AFFECTING THE AREA

The coastal margin of the Bay of Biscay has been inhabited since prehistoric times. The concentration of cave paintings in northern Spain (awarded status as a World Heritage Site by UNESCO in 2008) and the megalithic alignments of Carnac in Brittany are good examples of early human settlements in the area. Nowadays, the region has a population density close to the average of the EU (116.7 inhabitants per km^2), showing a clear increasing trend from West to East in Spain and from South to North in France (European Union, 2016a) (Table 5.7.). According to available data from 2014, the total population in the Spanish and French regions bordering the Bay of Biscay is more than 18 million.

TABLE 5.7 Eurostat Statistic Data on Socioeconomic Indicators for the European Union (EU) Regions Bordering the Bay of Biscay

	Population Density km^{-2}	GDP per Inhabitant[a]	Permanent Grassland Harvested Green	Coastal Tourism Nights Spent	R&D Intensity GDP on R&D
Galicia	93.4	79.92	78.9	59.8	0.87
Asturias	99.8	80.19	96.7	56.3	0.89
Cantabria	111.4	82.27	99.2	84.4	0.94
Basque Country	299.6	119.01	65.1	49.7	2.12
Aquitaine	81.3	91.95	46.8	53.8	1.60
Poitou-Charente	69.6	86.85	30.2	70.8	0.92
Pays de la Loire	115.4	95.18	58.2	62.3	1.22
Brittany	120.7	88.40	56.6	85.4	2.02
EU average	116.7	100		47.4	2.03
Spain	92.5	96			1.23
France	104.5	101			2.26

Source: Eurostat (data are for 2014; except R&D intensity which are for 2013).
GDP, Gross Domestic Product; *R&D*, Research and Development.
[a] *Percentage of the EU-28, EU28= 100.*
Data from European Union. (2016a). Eurostat regional yearbook edition 2016. ISBN 978-92-79-60090-6, 274 p.

The Bay of Biscay has experienced important changes in the coastal land use during the past 50 years mainly due to industrialization and urban development. Although land and coastal uses are still important resources, the economy in the entire region has an industrial tradition and in the past decades other emerging sectors such as tourism and research are also above or near the European average (Fig. 5.7. and Table 5.7.; statistical indices of development and human activities are published by the Eurostat on a yearly basis (see, e.g., European Union, 2016a). Regarding R&D expenditure (% of GDP), both Basque Country and Brittany are at the European average. Most of the regions bordering the Bay of Biscay have important Universities and dedicated marine research laboratories.

There is a romantic feeling of engagement by the people in the region with their ethnic roots, with the Celtic culture preceding the Roman Empire, and maritime commerce has connected the region for a long time (records of marine exchanges exist since circa 1303 and international agreements since 1353 (Arizaga, 2008). There are many examples of a common cultural tradition which is still noticeable in folkloric, food, and gastronomic elements [e.g., pipers, cider, and pancakes (filloas, frixuelos, crêpes)] which can be found from Galicia in Spain to Brittany in France.

In general, the disturbances produced by human activities can be stated as inputs of specific substances, physical disturbances, and direct impacts on biological communities and species. In the absence of a quantitative scale of the importance of impacts on the ecosystem in the Bay of Biscay, the effects of human pressure on the marine ecosystem (33 different impacts are described in Anon (1998)) are grouped here by type of human activity (human settlements, extractive activities, industrial activities, building and maintenance of infrastructures, and shipping and oil transport). Additional extensive reviews of the human impacts within the Bay can be consulted in Valdés and Lavín (2002) and Anon (2008).

5.4.1 Human Settlements

In the past century, human settlements in the coast have resulted in large populations with all the problems associated with urban agglomerations. Tourism, new urbanization of coastal areas, and recreational uses of beaches and shores have added pressure including the disposal of sewage. Ecological disturbances produced by human settlements include microbiological

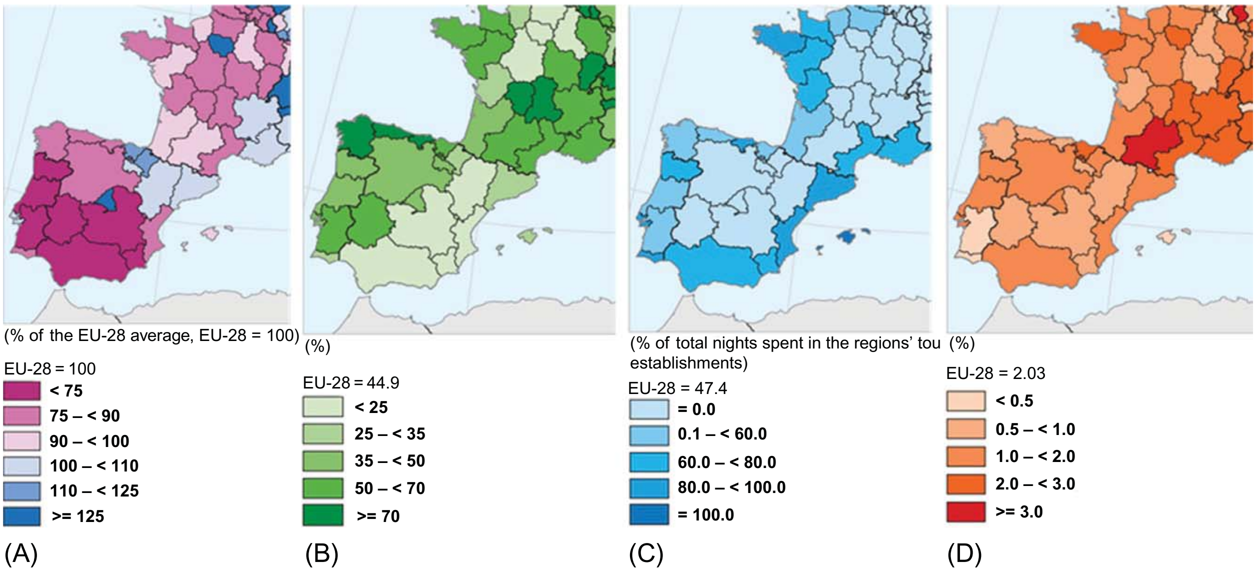

FIG. 5.7 Eurostat maps on socioeconomic indicators for the EU by NUTS 2 regions (data 2014): (A) gross domestic product (GDP) per inhabitant in purchasing power standard (PPS) in relation to the EU28 average; (B) Share of permanent grassland and plants harvested green in the total utilized agricultural area; (C) Coastal tourism, share of nights spent in tourism accommodation establishments in coastal localities; (D) R&D intensity, GDP expenditure on R&D (data 2013). *Data from European Union. (2016a). Eurostat regional yearbook edition 2016. ISBN 978-92-79-60090-6, 274 p.*

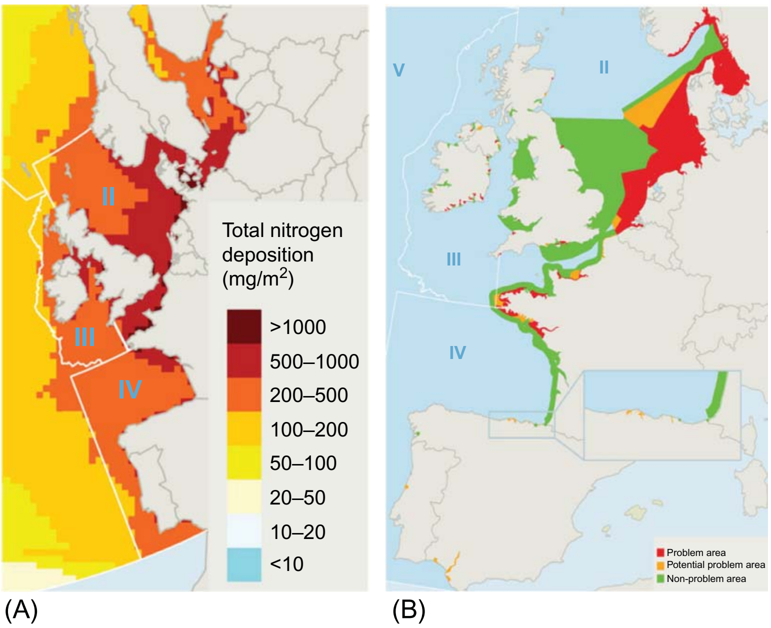

FIG. 5.8 (A) Total Nitrogen deposition and (B) eutrophication problem areas according to OSPAR (2010).

pollution, eutrophication, land reclamation, loss of habitats, and marine litter. Estuaries and coastal lagoons receive the main impact of microbiological contamination from urban sewage, which has a strong impact on the quality of bathing waters and on shellfish. Farming contributes almost two-thirds of waterborne nitrogen in bays and estuaries in Northern Brittany and the Bay of Biscay where eutrophication problem areas remain (OSPAR, 2010; Fig. 5.8.).

The implementation of the recent Directives from the EU on water treatment and monitoring (e.g., bathing waters directive and MSFD) depuration will result in a reduction of this kind of risk in the near future. Most of the data on floating debris or litter along the coast (particularly on beaches) refer to plastics, which constitute about 85% of marine litter because of their poor degradability. Although the human pressure is strong on the region, the risks derived from human settlements are not severe in the Bay of Biscay and only in some cases have local imbalances occurred.

5.4.2 Extractive Activities

Extractive activities include fishing, aquaculture, and farming. The ecological disturbances include a direct impact on target species, overfishing, alterations of the seabed, introduction of non-indigenous species, agriculture sewages, etc. The Bay of Biscay has traditionally been an area of intense fishing activities and nearly 5000 fishing boats operate in this region (European Union, 2016b). The catches in 2015 within the NE Atlantic, for Spain and France, were 362,345 and 382,856 t, respectively, after Eurostat data (http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tag00078&plugin=1). Trawler and purse seiners are the main fishing vessels used for demersal and pelagic species. The main species fished in the area are anchovy, sardine, hake, mackerel, horse mackerel, and tuna. Other gears used at a lesser extent are gill nets, lines, dragnets, etc. Fishing activities do not only affect the pelagic and demersal fish species, but also many intertidal populations are subjected to exploitation: clams, crabs, octopus, and many others. The sea urchin *Paracentrotus lividus* is intensively exploited on the north coast of Spain and its intertidal population has virtually disappeared from wide areas (this species is now restricted to tide pools and is made up of small-sized individuals). Aquaculture has greatly increased in the past decade and environmental risks associated with this activity are under debate. Society has been recently aware on the use of GMO (Genetically Modified Organisms), but the use of such organisms has not yet been reported in the Bay of Biscay.

5.4.3 Industrial Activities

Industrial activities have traditionally supported the economy of the Bay of Biscay in both France and Spain. Many of these activities are known to be polluting, for example, paper milling, petroleum refining, iron and steel working, chemicals, etc. Disturbances include industrial discharges and inputs of specific pollutants (both inorganic and organic compounds). Mercury is associated with paper mill industries and mining and it is recognized as being one of the most important inorganic pollutants, which remains as a particular problem in the Oslo-Paris Convention (OSPAR) region IV, with over 40% of sites having unacceptable levels in sediments (OSPAR, 2000, 2010). PAHs (Polycyclic Aromatic Hydrocarbons) may occur naturally but their concentrations increase significantly in some cases due to human activities: incomplete combustion, marine oil extraction, industrial discharges, oil traffic and handling, etc. There are important petrochemicals industries in the Bay of Biscay.

5.4.4 Building and Maintenance of Infrastructure

Building and maintenance of infrastructure are important factors and include coastal protection, land reclamation, dredging, and shipping. Sediments are often dredged in harbor areas, estuaries, and navigation channels. The dredged material is usually sand, silt, or gravel. The quantities of dredged material vary from year to year according to the patterns of sediment movement and accretion that make recurrent maintenance dredging necessary, as well as new projects for harbor development requiring capital dredging. Disposal of material from maintenance dredging of ports and navigation channels has a potential temporary and long-term impact on the bottom and water column of the disposal site because of the scale of the dumping and the general contaminated nature of the sediments. However, the amount of sediments dredged and disposed of in the Bay seems to be relatively small ($<20{,}000\,\mathrm{t\,year^{-1}}$), since 90% of the total sediments dredged in the OSPAR area come from the North Sea (OSPAR, 2010).

5.4.5 Shipping, Oil Drilling, and Transport

Shipping, oil drilling, and transport can produce unintentional pollution. Exploration for new oil and gas fields in the French part of the Bay of Biscay has been carried out on the continental shelf adjacent to the Aquitaine basin with some promising discoveries around the Arcachon basin. Recently, there has been renewed interest of oil companies in the Bay of Biscay continental shelf results in new seismic surveys in the North coast of Spain. Present targets are still located near onshore producing areas, with one platform operating in the inner part of the Bay (off Bermeo, Basque Country), which extracted natural gas in an area of limestone from 1986 until 1995, at a depth of between 2100 and 2700 m under a water depth of about 106 m. In 1995, it was converted for use as a store of gas imported from other countries.

Most importantly, the Bay of Biscay is located on the main route of supertankers transporting oil from the Middle East and Africa to EU harbors. More than 70% of the total oil consumed in the EU is moved by shipping through the Finisterre pass directly toward the English Channel and then to the final destination in different European harbors (Lavín et al., 2006; Fig. 5.9.).

For example, three supertankers carrying more than 50,000 t each have been wrecked in an interval of just a decade (1992, Aegean Sea; 1999, Erika; 2002, Prestige), which has made this region the most severely affected by this kind of accident in the world. In December 1992, the Aegean Sea broke up and exploded near La Coruña, spilling more than 70,000 t

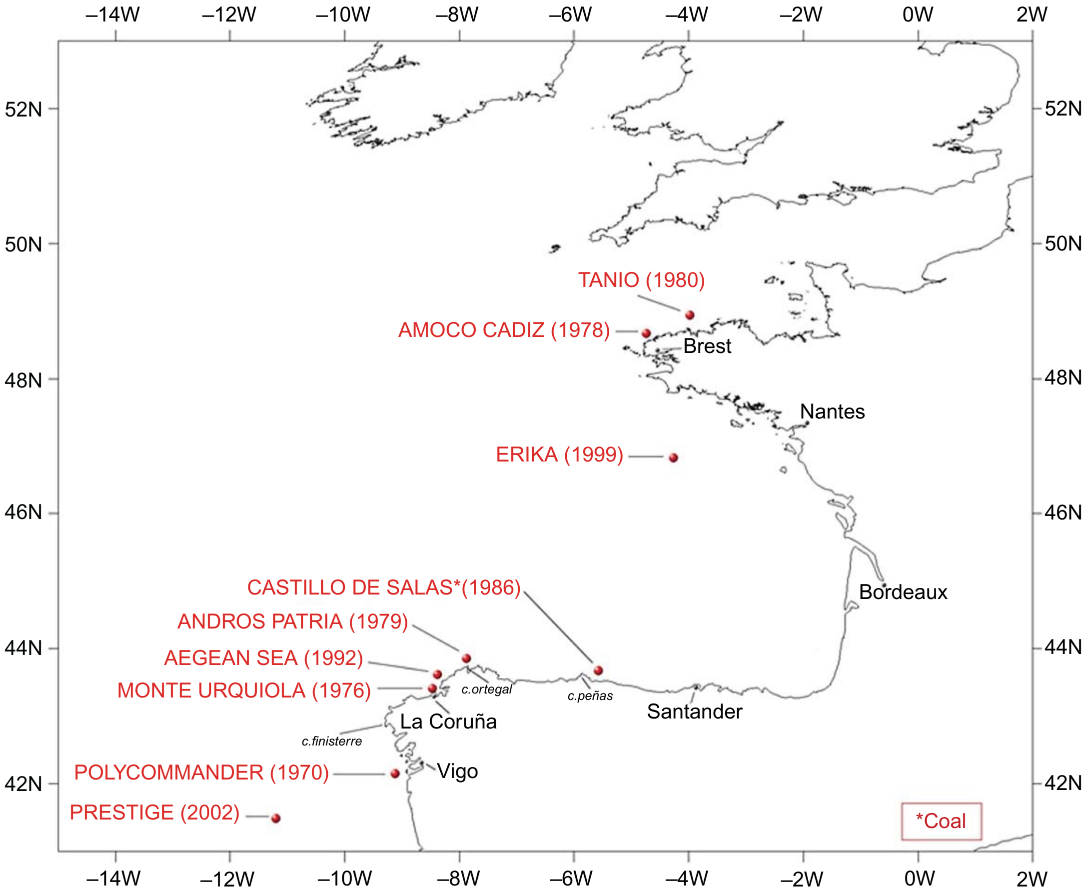

FIG. 5.9 Main oil spill events in the Bay of Biscay and its vicinities since 1970 with indication of the tanker's name and year of the spill. *Source: Lavín, A., Valdés, L., Sánchez, F., Abaunza, P., Forest, A., Bouucher, J., Lazure, P., Jegou, A.M. (2006). Chapter 24. The Bay of Biscay: The encountering of the Ocean and the shelf. In A.R. Robinson and K.H. Brink (Eds.). The Sea, vol. 14, pp. 933–1001; reproduced with permission of the authors).*

of oil into the water in a bay less than 50 m depth. In December 1999, the Erika was wrecked in the coast of France and 10,000 t of oil were spilled in shallow waters. The Prestige, wrecked in November 2002 about 200 miles offshore west of Galicia (outside of the Bay of Biscay), produced a black tide of more than 60,000 t which, due to the strong wind in the area, moved toward the Spanish coast and polluted the coast and large extensions of beaches, cliffs, fishing grounds, marine protected areas (MPAs), etc.

The NW Spanish coast and the Bay of Biscay on the route toward the English Channel is a high-risk area where the likelihood of new accidents is high and oil spills remain a real risk. The events monitored during recent years can be used as a basis for a better understanding of ecosystem response to these perturbations, as well as for preparing adequate action plans (Carballeira, 2003). Combining and coordinating the efforts of both Spanish and French experts and resources to preserve the quality of our environment is a challenge for both communities.

Although the surveillance on the marine ecosystem has improved substantially in the past 15 years (e.g., OSPAR Quality Status Report (QSR), MSFD, etc.), the information available on human impacts is still scarce, often restricted to inner coastal areas. It remains difficult to: (i) evaluate the environmental importance and the economic cost of man's uses of the marine ecosystem in the Bay of Biscay, and (ii) establish social and administrative priorities addressed to a rational management and sustainable use of the resources.

5.5 EFFECTS OF HUMAN ACTIVITIES

5.5.1 Metals

Trace metals refer to metals and metalloids and their compounds that can become toxic for organisms above a given concentration. They are mostly supplied in the Bay of Biscay as dissolved forms and particulate matter from the waterways throughout the drainage basin that flow toward the main rivers and estuaries. Some metals, such as mercury and lead, also may have a large atmospheric contribution. Metals are present in the environment at levels that can be defined as a geochemical background. Human activity has become an additional source of trace metals for both fluxes and new compounds, such as some organo-metals. The main sources of anthropogenic trace metals are industrial activity and wastewater, which has impacted urbanized coastal zones of the Bay of Biscay. Most of the recent literature on trace metals contamination in this area concerns transitional waters, and more specifically large estuaries such as the Loire, Gironde, Adour, and Nervion estuaries. In some cases, pollution has decreased significantly in the past 20 years (Borja et al., 2016).

5.5.1.1 Atmospheric Deposition

Atmospheric depositions of heavy metals have been assessed using an emission-based modeling approach and an atmospheric transport model in OSPAR (Nijenhuis, Van Pul, & De Leeuw, 2001). Generally, atmospheric deposition of heavy metals in the Bay of Biscay is a minor source in comparison with riverine and other sources (e.g., dumping, erosion). The deposition pattern is one of a decaying gradient from coasts to open waters with atmospheric fluxes at 500 km from the coast of about an order of magnitude lower than the deposition to coastal waters. For the Bay of Biscay and the Iberian Coast, the deposition mainly originates from Spain (29%–88%) and to a lesser extent from France, the U.K., and Portugal (summed: 7%–45%). Stationary combustion and mobile sources form the most important source categories. For chromium, cadmium, and zinc, a large contribution comes from the primary iron and steel industry and the nonferrous metal industry.

5.5.1.2 Continental Shelf and Slope

Sediment particles have been identified as key factors in metal/contaminants transport from the continent to the ocean and play an important role in the river basin and coastal area. They can act as a source or a sink of metal-bounded particles or dissolved metal, which can significantly increase the ecotoxicological impact. Sediments of the Bay of Biscay may be considered as the ultimate receptacle of marine organic/inorganic suspended particulate matter (SPM) and terrigenous inputs from estuarine and riverine watersheds. Few studies focus on trace metals in the deep sediment of the Bay of Biscay.

The regional geochemical baseline of the Bay of Biscay has been assessed from sediment cores long enough to record pre-industrial concentrations of particulate trace metals. One such dated core has been collected off the Gironde estuary in the western Gironde mud patch (Larrose et al., 2010). All metal concentrations remained below OSPAR background values (OSPAR, 2000) during the first part of the twenty century (Larrose et al., 2010), despite a very attenuated signal of Zn and Cu from the Gironde outputs (Boutier, Quintin, Rozuel, Dominique, & Bretaudeau-Sanjuan, 2011), suggesting that this area was not submitted to significant anthropogenic input of metals. Metal concentrations measured in sediment cores collected in deep parts of the Bay of Biscay continental margin between 150 and 2800 m depth showed that the distribution of As, U, Cd, and Mo was mainly controlled by early diagenetic redox processes, suggesting that variations in total metal concentrations should not be interpreted directly as a sedimentary record of metal transport to the sediment (Chaillou, Anschutz, Lavaux, & Schäfer, 2002; Chaillou, Schäfer, Anschutz, Lavaux, & Blanc, 2003). The non-redox-sensitive fraction deduced from selective leaching of particles did not show variations in sediment cores covering the past 250 year, suggesting that the transport of the studied metals to deep sediments of the Bay of Biscay has not been influenced by mining activities in the Adour/Garonne basin (Chaillou et al., 2003). Close to the Spanish coast, in the canyon of Capbreton, high lead and mercury concentrations were noticed in a 1977–1999 interval recorded in a sediment core (Boutier et al., 2011). Other metals (Cd, Cu, Zn, Ni, Cr) stayed at a much lower level. Lead had concentrations more than twice the OSPAR reference. Concentrations began to decrease after 1998, indicating a drop of lead input. This study showed that some metals may have been transferred to the deep-sea through the Capbreton canyon, which has been recognized as an active zone of particles focusing (Anschutz & Chaillou, 2009) and modern gravity processes of sediment deposition (Mulder, Weber, Anschutz, Jorissen, & Jouanneau, 2001).

Fishes (sole and hake) and sediments collected along the Basque continental shelf were found to be impacted moderately by metals (Cuevas et al., 2015). Metal bioaccumulation and histopathological lesions in the liver were not correlated with sediment contamination levels, suggesting that other factors, rather than pollution alone, were responsible for the biological effects observed (Cuevas et al., 2015).

5.5.1.3 Estuaries

The implementation of new environmental policies and regulations, together with the closure of major historical sources, has caused a considerable decrease of trace metal concentrations in large estuaries from the Bay of Biscay. The Nervion estuary (Bilbao) has been considered as the most polluted coastal area of northern Spain during the 20th century. This estuary is located in one of the most populated areas (~1 million inhabitants) on the Bay of Biscay, with numerous industrial and urban activities. The exploitation of local iron at the end of the 19th century and shipbuilding in the bay, together with an intense port activity, also have had a clear influence on the water quality of the estuary. During the past 150 year, the natural features of this estuary have been dramatically modified. However, a significant decrease in the flux of contaminants has occurred over recent decades due to the closure of some major factories, the implementation of environmental protection policies, and the improvement in waste-treatment systems in this and other Basque estuaries and coastal areas (Borja, Chust, et al., 2016). Temporal trends in metal concentrations measured in water samples (Gredilla, de Vallejuelo, Arana, de Diego, & Madariaga, 2012), sediments (Fernández-Ortiz de Vallejuelo, Arana, De Diego, & Madariaga, 2010), and soft tissues of *Mytilus galloprovincialis* mussels and *Crassostrea gigas* oysters collected from estuarine waters (Solaun, Rodríguez, Borja, González, & Saiz-Salinas, 2013) showed abrupt decreases in metal concentrations occurring between 1998 and 2002. This trend was related to increased wastewater treatment implemented mainly during 2000–2002 (Solaun et al., 2013). However, there are still some points of the estuary where concentrations of As, Cd, Cu, Pb, and Zn are significantly higher than the background values estimated for the area (Gredilla, Fdez-Ortiz, de Vallejuelo, de Diego, & Madariaga, 2013). These sediments may still pose a toxicological threat to living organisms.

Among other estuaries located in the northern coast of Spain, Suances is one of the most polluted in the Bay of Biscay (Coz, González-Piñuela, Andrés, & Viguri, 2007). The contamination comes from the Saja and Besaya rivers, which drain the Reocín deposit, one of the largest Zn–Pb ore deposits in Europe, where mining activities can be traced back at least to Roman times (Iglesias, 1995), when the estuary mouth was known as "Portus Blendium." From the middle of the 19th century until 2003, mineral deposits have been exploited continuously. Mining operations have extracted more than 60 Mt, with 8.7% Zn and 1% Pb, with relatively high concentrations of Cd in sphalerites (600 mg kg^{-1}) (Velasco et al., 2003), and several metal manufacturing factories were installed in the nearby area of Torrelavega. In 1935, the electrolysis of brine using a mercury cell was implemented in the local chlor-alkali industry. Concentrations of Zn, Pb, and Cd in sediment samples collected in the estuary are remarkably higher than background values, reflecting the impact of the mining and industrial polluted materials (Irabien, Cearreta, Leorri, Gómez, & Viguri, 2008).

The Gironde estuary is known to be impacted by metallic pollution (Blanc, Lapaquellerie, Maillet, & Anschutz, 1999; Jouanneau, Boutier, Chiffoleau, Latouche, & Philipps, 1990). Highly toxic metals such as Cd and Hg showed the highest enrichment factors relative to baseline. Historically, the main point source of trace elements within the Gironde Estuary watershed was identified in the upper part of the Lot River, 350 km upstream of the estuary, where a small tributary drains wastes from an old Zn-ore manufacturing facility (Audry et al., 2010; Audry, Schäfer, Blanc, Bossy, & Lavaux, 2004; Blanc et al., 1999; Coynel et al., 2009; Jouanneau et al., 1990; Schäfer & Blanc, 2002). The cessation of industrial activity in 1987 and intense remediation efforts have considerably decreased emissions (Castelle et al., 2007). Nevertheless, during a major flood of the Lot River in winter 2003, trace element fluxes due to remobilization of dam sediments were 270 t for Zn, 6.4 t for Cd, and 21.5 t for Pb (Coynel, Schäfer, Blanc, & Bossy, 2007). Agriculture and wastewater represent additional sources of trace metals to the Gironde estuary. High Cu concentrations in suspended particulate matter of some Gironde estuary tributaries have been assigned to vineyards (Masson, Blanc, & Schafer, 2006). Wastewaters from the city of Bordeaux (>600,000 inhabitants) may represent a significant source of some metals, such as silver (Lanceleur et al., 2011), which has been reported with high concentrations in mussels and oysters of the Gironde estuary (Chiffoleau, Auger, Roux, Rozuel, & Santini, 2005). During short intense summer rainstorms, the two main wastewater treatment plants of Bordeaux contained particulate and dissolved effluent concentrations up to 2 (Cr), 3 (Pb, Cu, and Ni), and 5 (Cd and Zn) times higher than measured upstream in the Garonne River, respectively (Deycard et al., 2014). This multielement contamination has resulted in high concentrations in oysters and mussels in and next to the Gironde Estuary (French National Mussel Watch, ROCCH, 2014) and interdiction of shellfish production in this area. Trace element concentrations in oysters of the Marennes-Oléron Bay, one of Europe's most important oyster producing zones located ~40 km to the north of the Gironde Estuary mouth, remain relatively high, compared to other sites along the French coast with Cd levels close to consumption thresholds [Cd: 5 $\mu\text{g g}^{-1}$, dry weight (DW)]. It has been shown that almost 100% of suspended particles of this area originated from the Gironde (Dabrin, Schäfer, Bertrand, Masson, & Blanc, 2014).

The Loire and the Adour estuaries represent the second and the third largest inflows to the Bay of Biscay. However, recent studies that examine their contribution to metals to the Bay of Biscay are rare (e.g., Sharif et al., 2014; Stoichev et al., 2004; Waeles, Riso, Cabon, Maguer, & L'Helguen, 2009), as they are not considered as a significant source of metal contamination.

To conclude, sediments of large contaminated estuaries have become a major reservoir for metallic contaminants, and provide a potential source for secondary pollution from mechanical effects, such as floods or dredging, and/or biogeochemical remobilization. However, an improvement in environmental conditions is occurring along the coast of the Bay of Biscay due to changes in human pressures and management actions (Borja, Chust, et al., 2016). This has noticeable results from, among other parameters, long-time series of wild mussel monitoring (Besada, Sericano, & Schultze, 2014). Ranges of metal concentration measured in wild mussels at different coastal locations are presented in Table 5.8.

TABLE 5.8 Trace Metal Concentrations in Mussels From Similar Monitoring Studies (Values in $mg\,kg^{-1}$ dry Weight)

Location	Hg	Cd	Pb	Cu	Zn	As
Galicia and Cantabrian (NW Spain)	0.06–0.62	0.36–2.01	0.66–28.1	3.9–9.9	141–361	6.4–13.3
Galicia and Cantabrian (NW Spain)	0.04–0.61	0.38–4.54	0.57–26.6	3.9–10.1	145–470	8.4–17.2
Galicia and Bay of Biscay (NW Spain)	0.10–0.61	0.43–4.54	1.7–26.6	3.5–14.1	143–423	
Basque coast (N Spain)	0.28–0.70	0.70–1.33	1.1–5.8	13–20	353–580	1.3–2.5
Atlantic coast/Bay of Biscay (W France)	0.03–0.53	0.17–3.03	0.4–9.6	4.0–23	36–406	

Adapted from Besada, V., Sericano, J.L., Schultze, F. (2014). An assessment of two decades of trace metals monitoring in wild mussels from the Northwest Atlantic and Cantabrian coastal areas of Spain, 1991–2011. Environment International 71, 1–12.

5.5.2 Focus on Mercury and Organic Pollutants

5.5.2.1 Mercury

Among toxic metals identified as potential contaminants in the Bay of Biscay, mercury has been recognized as an important pollutant in this area. While various coastal sources and biogeochemical pathways have been investigated to evaluate the background contamination of sensitive ecosystems, several studies have been focused on the accumulation of Hg in marine sediments and food chains of the Bay of Biscay.

Major Hg pollution in the Bay of Biscay is driven by river discharge into the bay, while atmospheric fallout remains an important source also. Methylmercury (MeHg), a bioaccumulated and biomagnified neurotoxin, is mainly formed in aquatic systems, and both river derived MeHg inputs and in situ formed MeHg may account for Hg accumulation in the marine food chain. River discharge from the Adour estuary has been documented, and showed that an effective input of MeHg occurs along the Basque coast, while its transport down to the oceanic area remains to be demonstrated (Sharif et al., 2014).

In marine sediment, Hg has been poorly investigated within the Bay of Biscay but more intensive studies have been conducted in coastal environments. For instance, Hg and other metal accumulation in large sediment deposits have been investigated (Boutier et al., 2011) using core samples off the Gironde estuary mouth and close to the Basque coast (Capbreton Canyon). This retrospective study highlights significant Hg contamination from 1977 to 1992 which remains elevated in recent years. Similarly, a direct transfer of Hg continental inputs has been found in coastal and shelf sediments along a transect from the inner Adour estuary to the shelf break, including an effective transport of MeHg to the coastal marine area (Stoichev et al., 2004) For coastal areas, it has been shown that superficial sediments in Arcachon Bay are significant sources of MeHg that can be remobilized into the water column through diffusive fluxes or tidal pumping (Bouchet et al., 2013).

Hg accumulation in coastal and marine food chains has some important impacts on fisheries. The Spanish “mussel watch” along the Bay of Biscay has recorded in Cantabria significant levels of Hg due to historical anthropogenic inputs usually exhibiting a regular decrease since 1991 (Besada et al., 2014). While in estuaries target species such as yellow eels (*Anguilla anguilla*) are directly impacted to significant levels ($\geq 1\,mg\,kg^{-1}$ DW) by anthropogenic inputs (Arleny et al., 2007), more demersal fishes such as hake (*Merluccius merlucius*) have been found to accumulate lower levels of Hg ($<1\,mg\,kg^{-1}$ DW) as controlled by their trophic levels and growth rate (Cossa et al., 2012). On the other hand, deep sea fish (and fauna) revealed much a higher concentration of Hg (up to $5\,mg\,kg^{-1}$ DW) independently of their trophic position but in relation to their habitat and feeding zone, suggesting a potential risk for human consumption of such deep sea organisms (Chouvelon et al., 2012). Other predator organisms such as cephalopods have been found to accumulate significant levels of mercury for both benthic and pelagic feeders (Bustamante, Lahaye, Durnez, Churlaud, & Caurant, 2006).

While European emissions of Hg have been steadily decreasing since the early 1990s, Hg global emission resulting from efficient atmospheric transport and fallout in the northern hemisphere remains high. On the basis of recent assumptions that most Hg accumulation in marine organisms is related to in situ production within the marine water column, we may expect that Hg pollution in the Bay of Biscay, although not very significant, could still be a threat to specific marine food chains.

5.5.2.2 Organic Pollutants (Including Oil Spills)

A few studies have been dedicated to persistent organic pollutants (POPs) in the marine system of the Bay of Biscay, though much more work has been done in coastal bays and estuaries in relation to the direct impact of continental anthropogenic inputs. To date, polycyclic aromatic hydrocarbons (PAHs) have been studied in the marine section of the Bay of Biscay following important oil spills that occurred during shipwrecks (e.g., Erika 1999, Prestige 2002, etc.). Further, many other anthropogenic inputs have been monitored through national coastal surveys in both France (*Réseau d'Observation de la Contamination Chimique du milieu marin*) and Spain (in this case, there are several, depending on the regional governments, e.g., Borja, Chust, et al., 2016) following the European Water Framework Directive (WFD) and international conventions (e.g., OSPAR).

In the past 30 years, attention has been paid to organotin and especially tributyl-tin (TBT) pollution due to their extensive use as biocides for antifouling paints. Several coastal areas and marinas in the Bay of Biscay have been impacted by TBT pollution (e.g., Arcachon Bay) but, since the ban of the use of this compound and other organotins, their concentrations in water, sediment and biota in estuarine and coastal systems have been steadily decreasing (Cavalheiro et al., 2016; Monperrus et al., 2005).

Chronic sources of organic pollutants are mainly related to urban and industrial effluents even where treatment plants' capacity, technology, and efficiency have improved in recent years. Several investigations have addressed the sources, fluxes, and eventually the risk related to organic micropollutant inputs in coastal areas. Both priority POPs, reactive and emerging contaminants, should be now evaluated, as mixed chemical pollution may have a significant impact on marine ecosystems. In this sense, it is possible to establish spatially resolved pollution assessments in PAHs, polychlorobiphenyls (PCBs), plasticizers (phthalates, bisphenols), alkylphenols, organochlorine pesticides, and polybromobiphenyl ethers (PBDEs). These studies have been carried out, for example, in the Cantabrian Sea in water, sediments, and biota samples and have demonstrated strong pollution gradients due to urban and industrial effluents (Sánchez-Avila et al., 2013). This has allowed the provision of chemical risk indexes that can be helpful for future environmental guidelines and regulations. In the marine ecosystem of the Bay of Biscay, significant concentrations of PAHs have also been detected in both surface waters and overlying air (ca. $1\,\mathrm{ng\,L^{-1}}$ and $2\,\mathrm{ng\,m^{-3}}$, respectively) (Nizzetto et al., 2008). Such higher concentrations, when compared to other open ocean systems, are not completely understood but might be related to either intentional or unintentional oil release from the intense ship traffic across the bay or from more diffuse atmospheric inputs.

Accidental sources in the Bay of Biscay over a large scale are mainly due to tanker shipwrecks that can release large amount of PAHs and other derivatives. In this sense, the Erika wreck in December 1999 impacted a large marine and coastal zone in the North of the Bay of Biscay which now has higher concentrations of many PAHs together with alkyl substitutes and sulfur heterocycle compounds in waters, suspended particulate matter, sediments, and intertidal molluscs (Tronczyński et al., 2004). As a consequence, heavily contaminated shorelines were in turn becoming potential sources of contamination. After the Prestige wreck (2002), which mainly affected the southern coast of the Bay of Biscay, several studies investigated the medium-term impact of oil pollution toward marine organisms (e.g., "mussel watch") using specific biomarkers highlighting genomic or physiological response to such anthropogenic stress. A recent overview of such an approach (Marigómez et al., 2013) demonstrated that a large impact was recorded during the year following the oil spill, while a recovery trend appeared in spring 2004 in most of the impacted location. Altogether, several studies have demonstrated that chemical contamination due to large oil spill accidents lead to intense and long-term contamination mainly from PAHs and other derivatives and to severe threat to coastal and marine ecosystems of the Bay of Biscay.

5.6 CONSERVATION AND STATUS ASSESSMENT

5.6.1 Marine Protection

Although oceans and coasts cover 72% of the earth's surface and constitute a major part of the planet that supports life, drives the climate, and provides vital resources, ocean and coastal issues have unfortunately received low visibility and priority at the global scale (UK National Commission for UNESCO Secretariat, 2015), and this is also true for the Bay of Biscay (EEA, 2012). Many ocean entities in Spain and France are sector-oriented and therefore fragmented (fishing, shipping, offshore oil and gas, offshore renewable energy, etc.), leaving little room for integral conservation approaches within the whole coastal/ocean stakeholders.

In recent years, several science-policy initiatives to facilitate status assessments on the marine environment were launched in both the UN system (e.g., World Ocean Assessment, Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services) and at the regional—European—level (e.g., OSPAR QSR, MSFD). The science-policy initiatives and status assessments translate scientific knowledge into a more accessible and understandable language and provide comprehensive information on the issues demanded by the conventions and the intergovernmental organizations, so that the latest scientific findings are reflected in high-level policy discussions (e.g. Conference of the Parties—COPs—and other governing meetings).

Periodic status assessments (such as the MSFD) are instrumental to mobilize the resources in the Bay of Biscay to monitor the status of the marine environment and to provide the information needed for better management. Partially underpinned by the information collected for the MSFD and the EU marine policy, the European Parliament has launched the directive 2014/89/EU establishing a framework for maritime spatial planning (MSP) (European Union, 2014). MSP is defined as the public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process (Ehler & Douvere, 2006). It is linked to ecosystem-based management, the ecosystem approach to fisheries (FAO, 2003), MPAs, and similar endeavors that have the potential to assist in managing conflicts through participation among diverse stakeholders (Ehler & Douvere, 2009). Managing space use conflicts between sectors is an increasingly important issue in the Bay of Biscay.

One important global regulatory instrument that may boost responses to loss of biodiversity and ocean acidification is the establishment of MPAs. The establishment of representative systems and networks of marine management areas is regarded internationally and nationally as one of the most effective mechanisms for protecting biodiversity and a tool for resource sustainability as MPAs increase resilience and alleviate pressure from various stressors. This includes, but is not limited to, well-connected and representative networks of MPAs. Some protection frameworks (MPAs, Biosphere reserves, Natural parks) have been put in place in some locations in the Bay of Biscay (e.g., Cabo Peñas, El Cachucho, Urdaibai, Marismas de Santoña, Arcachon Bay et Cap Ferret, Golfe du Morbihan, etc.; Fig. 5.10.). As a group, these sites represent a broad range

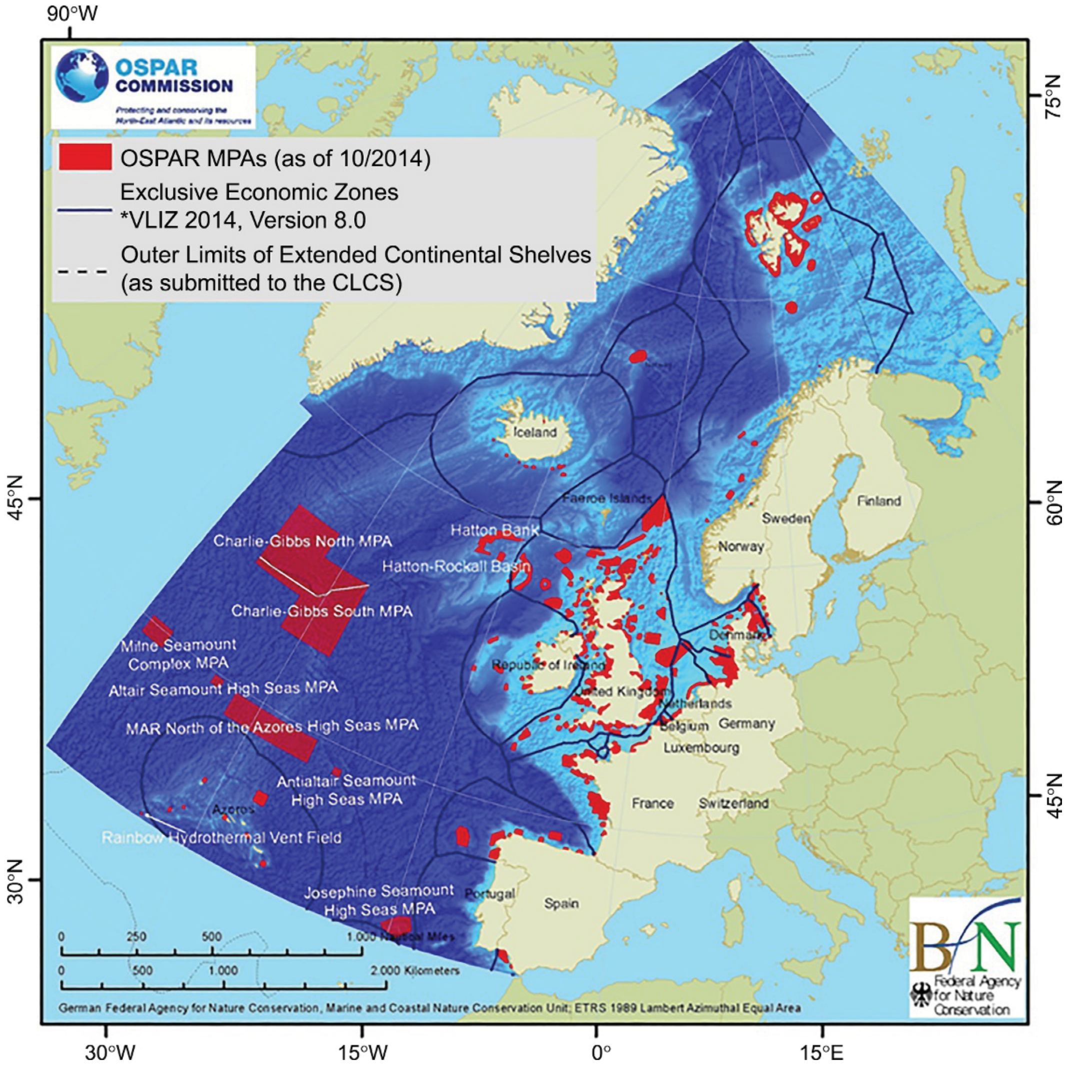

FIG. 5.10 Oslo-Paris (OSPAR) convention marine protected areas (MPAs) and the exclusive economic zones (EEZs) of OSPAR CPs (as of October 1, 2014). *Source: OSPAR (2015). 2014 status report on the OSPAR network of marine protected areas. OSPAR Commission, Biodiversity and ecosystem series, ISBN 978-1-909159-80-8, 64 p.*

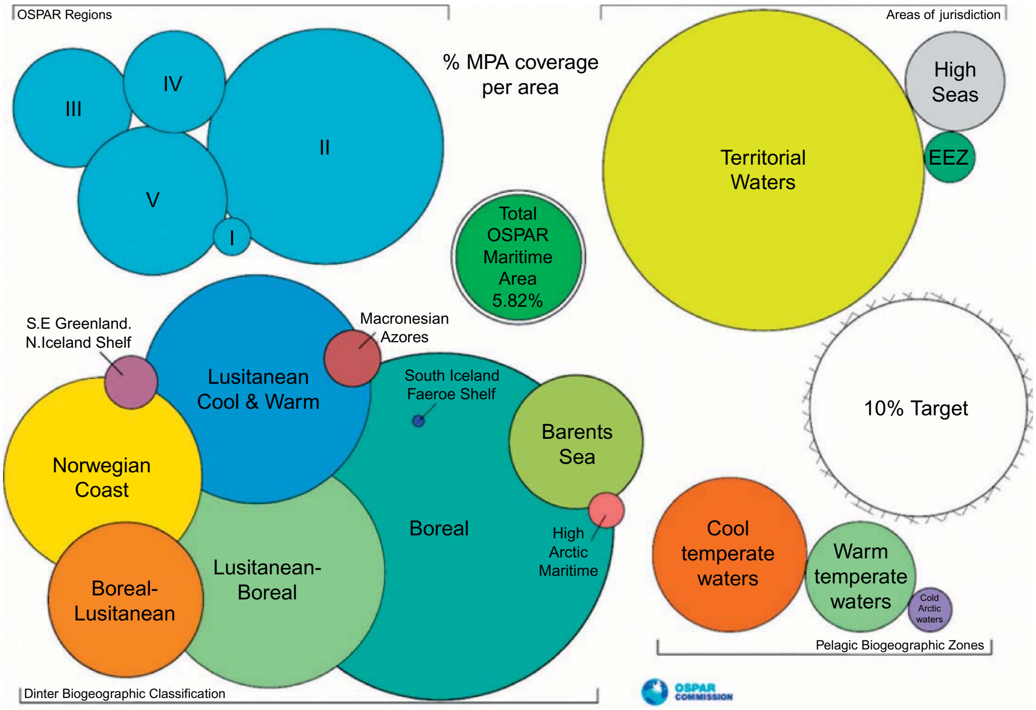

FIG. 5.11 Representation of the relative protection of the OSPAR maritime area with a view toward reaching the target set by Convention of Biological Diversity to protect at least 10% of coastal and marine areas by 2020 (as of October 1, 2014). *Source: OSPAR (2015). 2014 status report on the OSPAR network of marine protected areas. OSPAR Commission, Biodiversity and ecosystem series, ISBN 978-1-909159-80-8, 64 p.*

of species diversity, habitats, and ecological regimes (oceanic, coastal, estuaries, and salt marshes) in the marine environment, and are perhaps stabilizing or, in some cases, reversing the negative impacts of human impacts/stressors. It must be noted that, according to data provided by OSPAR, the region is falling behind the Convention of Biological Diversity target of 10% of territory protected (see region IV in Fig. 5.11.). However, studies and efforts to increase the number of MPAs in the Bay of Biscay are ongoing in areas within national jurisdiction (e.g., Aviles Canyon). Institutional frameworks for the identification and implementation of MPAs at regional scales are also well established in France (Agence des aires marines protégées, within the Ministère de l'Environnement, de l'Energie et de la Mer) for the development of management plans and in enforcing the regulations that may be required.

5.6.2 Ecosystem Services Provided

Although some small-scale studies on ecosystem services have been undertaken (Pascual et al., 2011), there is a lack of studies covering the whole bay, and normally they are of larger scale, embedding the Bay of Biscay. Hence, Liquete, Zulian, Delgado, Stips, and Maes (2013), when assessing coastal protection as an ecosystem service in Europe, included this area and considered that the services provided here by coastal protection are mainly deficient, with some areas sufficient and very few plentiful.

However, the most complete study on ecosystem services provided by benthic habitats in the area is that of Galparsoro et al. (2014), which includes provisioning, regulating, cultural, and total values (Fig. 5.12.).

Although the study mostly focuses on the continental platform (with large abyssal parts absent), it can be seen that the provisioning services are of high importance within the Bay, with moderate regulating services value and low cultural values.

5.6.3 Environmental Status Assessment

Until the approval of the MSFD, the most comprehensive quality status report was that undertaken by OSPAR (2010), detecting: (i) no problems with radionuclides and the oil and gas industry; (ii) some local problems related to eutrophication and hazardous substances (with some progress to achieve objectives); (iii) many problems related to fishing and the

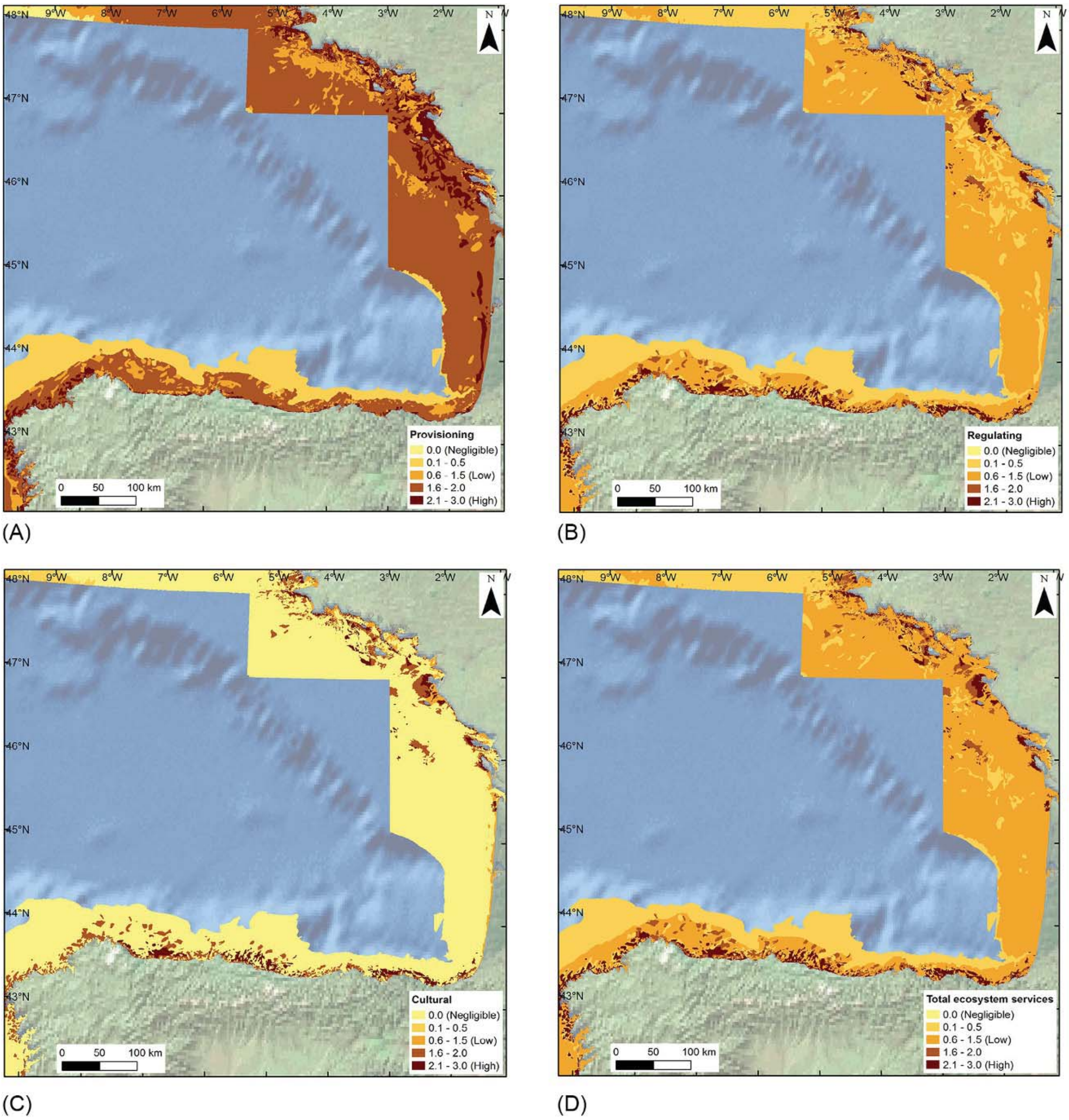

FIG. 5.12 Spatial distribution of the mean value of aggregated ecosystem services in the Bay of Biscay: (A) provisioning services; (B) regulating services; (C) cultural services; and (D) total ecosystem services. *Extracted from Galparsoro, I., Borja, A., Uyarra, M.C. (2014). Mapping ecosystem services provided by benthic habitats in the European North Atlantic Ocean. Frontiers in Marine Science 1, doi: 10.3389/fmars.2014.00023.*

status of some fish stocks, bycatch and damage to the seafloor, and also problems in relation to biodiversity. However, an integrative assessment (*sensu* Borja et al., 2016) was not undertaken due to the absence of adequate indicators, reference conditions and targets to determine what a good environmental status should be (Borja et al., 2013).

In turn, the first status assessment, applying the principles of the MSFD, was implemented in the Bay of Biscay (Borja et al., 2011). In line with the OSPAR (2010) findings, these authors determined that although the environmental status was good (0.68, on a scale from 0 to 1), the main environmental problems in the south-eastern part of the Bay were related to Descriptor 3 of the directive (commercial fisheries), propagating this non-good quality to Descriptor 4 (food-webs) and, to some extent, to Descriptor 1 (biodiversity).

France and Spain reported in 2012 on the initial assessment and environmental status of the Bay of Biscay [see http://rod.eionet.europa.eu/obligations/608/overview and AEVAL, 2012], as well as on the programs of measures [same web and Anon, 2014]. However, as in the case of OSPAR, the lack of suitable indicators and targets prevented the undertaking of an integrative assessment, and instead reports a good collation of the data available in the subregion, but without assessing the status. Currently, Member States and OSPAR are developing and testing those indicators for the next assessment, expected in 2018.

With updated data and new tools, some European projects have undertaken assessments in Regional Seas. Using the Nested Environmental status Assessment Tool (NEAT) (Borja, Elliott, et al., 2016), Uusitalo et al. (2016) assessed the status of 10 case studies across Europe, one being the south-eastern Bay of Biscay. Again, the status was good, while detecting some problems with fishing and biodiversity.

5.7 PERSPECTIVES

5.7.1 Climate Change

5.7.1.1 Trends in Temperature and Salinity

According to the IPCC Fifth Assessment Report (IPCC, 2014), approximately 90% of the energy accumulated by the Earth during the past decades is stored in the world oceans. Changes are more intense near the surface, with a trend on the order of 0.011°C year^{-1} over the period 1971–2010. Salinity is also an important variable since it is a proxy for changes in the water cycle over the ocean.

In the particular case of the Bay of Biscay, we have reviewed the studies carried out in the area at three different depths: near surface, intermediate waters, and deep waters.

Near surface water properties undergo remarkable intra and interannual changes, so it is difficult to establish robust trends. However, sampling is much more frequent at this depth. Macroscopically, surface water at the Bay of Biscay has warmed over the past decades at a rate ranging from 0.02 to 0.07°C year^{-1} depending on the area and the period under study (Chust et al., 2011; Goikoetxea, Borja, Fontán, González, & Valencia, 2009; Gómez-Gesteira et al., 2011; Gómez-Gesteira, deCastro, Álvarez, & Gesteira, 2008; González-Pola, Lavín, & Vargas-Yáñez, 2005; González-Taboada & Anadón, 2012; Koutsikopoulos, Beillois, Leroy, & Taillefer, 1998; Llope & Anadón, 2007; Michel et al., 2009; Planque et al., 2003; Valencia, Borja, Fontán, Pérez, & Ríos, 2003; Woehrling, Lefebvre, & Lehoerff, 2005). Costoya, de Castro, Gómez-Gesteira, and Santos (2015) analyzed SST over the period 1982–2014, finding that the warming is mainly due to the increase in the duration of the warm season. This fact is mainly responsible for the increase in the frequency of extreme hot SST days measured in spring (1.16 ± 0.23 days dec^{-1}) and autumn (1.81 ± 0.42 days dec^{-1}). However, warming has not been permanent over the 20th century where several cooling-warming cycles have been observed (deCastro, Gómez-Gesteira, Álvarez, & Gesteira, 2009; García-Soto et al., 2002; González et al., 2010). Coastal warming trends increase from Galicia to Brest with a marked seasonal component, being only significant during spring and summer (Gómez-Gesteira et al., 2008). Salinity shows strong interannual fluctuations, without a clear trend (González-Pola et al., 2012).

Intermediate waters have also experienced important changes over the past decades. González-Pola et al. (2005) detected that ENACW has warmed over the period 1994–2001 as a consequence of the deepening of the isopycnal levels with a mean warming trend of 0.032°C year^{-1}. They also noticed that both temperature and salinity of Mediterranean Water (MW) have increased over the same period at a rate of 0.020°C year^{-1} for temperature and 0.005 for salinity. Llope et al. (2006) found a decrease in salinity on the order of −0.004 year^{-1} at 300 depth over the period 1993–2003, showing the imprint of the Iberian Poleward Current on salinity. Gómez-Gesteira et al. (2013) observed that ENACW warmed and became more saline over the period 1975–2010 at a maximum rate of 0.011°C year^{-1} and 0.003 year^{-1}, respectively. Costoya, de Castro, and Gómez-Gesteira (2014) and Costoya, DeCastro, et al., 2014 consider a much shorter period (2004–2013) and use Argo floats to find that ENACW warmed and became more saline at a rate of 0.012°C year^{-1} and 0.004 year^{-1}, respectively. They also noticed that MW has cooled and freshened at a rate of −0.011°C year^{-1} and −0.005 year^{-1}, respectively. Changes were observed to be mainly due to variations in water masses than to displacements in the isopycnals.

Finally, the variability of deep waters (below the 2000 dbar) along the Cantabrian Sea is very small as observed by Prieto et al. (2015).

5.7.1.2 Sea Level Rise

According to the IPCC Fifth Assessment Report (IPCC, 2014), the global mean sea level rose by 0.19 m over the period 1901–2010, which results in an approximate rate of 1.7 mm year^{-1}. In addition, the rise since the mid-19th century has been observed to be larger than during the past two millennia. The sea level is projected to rise at a higher rate over this century.

The situation within the Bay of Biscay is similar to the one observed at the planetary scale. Table 5.9. summarizes the different studies carried out in the area.

5.7.1.3 Storm intensity, Frequency, and Duration

Apart from mean changes in sea level, the IPCC Fifth Assessment Report (IPCC, 2014) also concludes that climate change might affect the intensity, frequency, and duration of extreme events such as floods and storms. The analysis carried out at the eastern Bay of Biscay over the period 1980–1998 (Dupuis et al., 2006) shows that wave height tends to decrease. On the other hand, Borja, Fontán, and Muxika (2013) analyzed the Basque coast finding that the number of waves higher than 5 m has increased significantly over time. In addition, Cid et al. (2016) analyzed long-term trends in frequency, intensity, and duration of extreme storm surges in parts of the Bay of Biscay, showing that while intensity shows a significant moderate increase, both frequency and duration show a significant decrease. In the case of frequency, the decrease can be intense in the central part of the Bay. These authors also point out that that extreme storm surges can be more affected by interannual and decadal variability than by climate variations at longer timescales.

5.7.2 Challenges

The Bay of Biscay is going to face multiple challenges in coming decades. In addition to the global change shown in the previous section, sustainable development will depend on our ability to manage future ocean changes. In the coming years (it is already happening), social pressure will encourage policymakers to reach agreements regarding limits on carbon emissions and set up planetary boundaries for other anthropogenic impacts (Valdés, Fonseca, & Tedesco, 2010).

The current environmental crisis has examined the good or bad governance of our global commons and has raised worries about its effectiveness. In the past, we have managed the ecosystems by looking at individual species; now we look to the entire ecosystem. Also, ecosystem management has historically seen humans as being independent of ecosystems; now we see humans as an integral part of ecosystems. In short, over time, environment policies have evolved from being very targeted to being more holistic, which implies more knowledge demands, in particular to characterize the added complexities and uncertainties of integrated issues having long-term consequences (IOC/UNESCO et al., 2011).

TABLE 5.9 Rate of Sea Level Rise (mm year^{-1}) Within the Bay of Biscay

Location	Method	Time Period	Rate (±SE) (mm year^{-1})	Source
La Coruña	Tidal gauge	1943–2001	2.52 ± 0.09	Marcos, Gomis, Álvarez-Fanjul, Pérez, and García-Lafuente (2005)
Santander	Tidal gauge	1943–2004	2.08 ± 0.33	Marcos et al. (2005)
Santander	Tidal gauge	1993–2004	2.67 ± 3.24	Chust et al. (2009)
Bilbao	Tidal gauge	1993–2005	2.98 ± 1.08	Chust et al. (2009)
St Jean de Luz	Tidal gauge	1942–2006	2.09 ± 0.42	Chust et al. (2009)
Brest	Tidal gauge	1890–1980	1.3 ± 0.5	Chust et al. (2009)
Brest	Tidal gauge	1980–2004	1.3 ± 0.5	Wöppelmann, Pouvreau, and Simon (2006)
Bay of Biscay (open water)	Satellite altimetry and tidal gauge	1993–2002	3.09 ± 0.21	Wöppelmann et al. (2006)
Bay of Biscay (open water)	Satellite altimetry	1993–2005	2.7	Marcos, Woepelmann, Bosch, and Savcenko (2007)
Basque coast	Foraminifera-based transfer functions	20th century	2.0	Leorri, Horton, and Cearreta (2008)
Basque coast	Foraminifera-based transfer functions	20th century	1.5	Leorri and Cearreta (2009)

Adapted from Chust, G., Borja, A., Caballero, A., Irigoien, X., Sáenz, J., Moncho, R., Marcos, M., Liria, P., Hidalgo, J., Valle, M., Valencia, V. (2011). Climate change impacts on coastal and pelagic environments in the southeastern Bay of Biscay. Climate Research 48, 307–332.

The Rio +20 final outcome document, The Future we Want,[1] provided priorities in the form of recommendations in the areas of fisheries and marine pollution/marine environment protection, which are common to all on our planet, including the Bay of Biscay. Further, the recently approved SDG 14 Conserve and sustainably use the oceans, seas and marine resources for sustainable development[2] also provides guidelines on pressing issues and management priorities.

If real progress is to be made toward reversing coastal and marine degradation in the face of the accelerating man-made impacts, it is urgent that we adopt strategies toward science for sustainability. The UN SDG 14 also provides the ground to establish some new large international research programs following the legacy of other past successful initiatives. Science and innovation will underpin the blue economy growth, so the private sector needs to work closely with the marine scientific community to maximize the opportunities.

5.7.2.1 Pressing Issues Within the Bay of Biscay

There are several key issues that can compromise the status of the Bay of Biscay.

Mercury: Mercury remains as a particular problem in OSPAR region IV, with over 40% of sites having unacceptable levels in sediments, perhaps as a legacy of past mining activities. In general, pollution from hazardous substances is found in coastal locations close to urban and industrial areas.

Les marées vertes en Bretagne: Some estuaries and bays in Northern Brittany and the Bay of Biscay remain eutrophication problem areas. Farming contributes almost two-thirds of waterborne nitrogen in bays and estuaries. Algal blooms lead to oxygen deficiency and to the formation of toxic hydrogen sulfide (H_2S). It can take decades for ecosystems to respond to the reduction of nutrient releases.

Biodiversity: The Bay of Biscay has threatened or declining species, including sharks, skates and rays, seabirds, whales, diadromous, and commercial fish species. Human activities threaten the extent and condition of several seabed habitats, with fishing a key pressure. The Bay of Biscay is rich in cold-water corals and other deep sea habitats, which will be under pressure in coming decades, because of the increasing deep-sea mining (Boschen, Rowden, Clark, & Gardner, 2013) and fisheries (Clark et al., 2016; St. John et al., 2016). Better monitoring of marine biodiversity, both in the wider environment and in protected areas, is needed.

Invasive species: Control of invasive species is a challenge. Owing to growing maritime traffic and other activities (e.g., aquaculture), the number of exotic species is expected to increase. The problem already exists with a number of examples of invasive species in the Bay of Biscay (Zorita et al., 2013). The authorities are aware of the situation, and the implementation of the Ballast Water Convention is critical.

Global warming is becoming the central environmental concern of our time. More and new research has to be done to fully understand and evaluate the impacts of climate change in the Bay of Biscay and to cooperate internationally to monitor the effects of CC and Ocean acidification.

5.7.2.2 Challenges for the Bay of Biscay

The Bay of Biscay is facing some management and governance challenges to be solved in coming years, to ensure the sustainability of activities in the Bay and the delivery of services provided by this ecosystem.

Obtaining *data with a better spatial and temporal resolution* is a crucial and necessary step to take the pulse of the ocean and then keep it under permanent review (Valdés, 2012; Danovaro et al., 2016).

Develop coordinated spatial planning. The limited extent of the continental shelf in the Bay of Biscay, especially around the Iberian Peninsula, and the demand for space for human activities including marine renewable energy developments and mean improved marine spatial management are particularly urgent in the area (Suárez de Vivero & Rodríguez Mateos, 2012; Trouillet, Guineberteau, de Cacqueray, & Rochette, 2011).

Expand the MPA network. In the Bay of Biscay, there is a need to build upon the MPAs that have been established so far, to ensure that ecologically important areas are protected and form part of a network covering in the first phase 10% of its territory as indicated by the Convention of Biological Diversity and the EU Strategy of Biodiversity.

Promote sustainable fishing. The EU must promote the development of fisheries management plans that address depleted stocks, and encourage the collection of data to support the management of mixed fisheries.

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1. http://www.un.org/disabilities/documents/rio20_outcome_document_complete.pdf.
2. https://sustainabledevelopment.un.org/focussdgs.html.

The *governance* of oceans is fragmented (fishing, shipping, offshore oil and gas, offshore renewable energy, etc.) as if we were managing separate entities. There is a need for an international framework of cooperation for the Bay of Biscay on both ocean research and governance (IOC/UNESCO et al., 2011).

The success of *international instruments* (e.g., Regional Seas Conventions, WFD, MSFD), which contain commitments to reduce the human impact on the ocean and marine ecosystems (e.g., ballast water), depends heavily on the decision of governments and states; and there is a clear need for adequate and coordinated implementation of international reporting processes and conventions in the Bay of Biscay. All of this should result in better and coordinated monitoring and assessment of the area, under an ecosystem-based approach to management (Borja, Elliott, et al., 2016).

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WORLD SEAS

AN ENVIRONMENTAL EVALUATION

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EDITED BY CHARLES SHEPPARD

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Charles Sheppard is Emeritus Professor in the School of Life Sciences at the University of Warwick, UK. He has also worked for a range of United Nations, governmental, and aid agencies in tropical marine and coastal development issues. He has advised several governments on marine and coastal management and science, including the UK Government on its tropical overseas territories. He organized and led the scientific input to the 2010 creation of the world's largest fully protected marine area in the Chagos Archipelago, Indian Ocean. He has received several awards for his scientific contributions to marine conservation and has been editor of leading marine science journals for over 25 years.

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