Large Marine Ecosystems of the North Atlantic
K. Shennan and H.R. Skjoldal (Editors)

10

Dynamics and Human Impact in the Bay of Biscay: An Ecological Perspective

Luis Valdés and Alicia Lavín

INTRODUCTION

Geographically, the Bay of Biscay constitutes a geomorphological unit charact3erised by presenting a break in the north-south direction of the eastern Atlantic's continental margin (Figure 10-1). This break produces an inlet in the coastal topography occupying a surface area of approximately 175,000 km2. The coastal margin of the Bay of Biscay has been inhabited since prehistoric times and nowadays the region has a population density in the average of the EU (113 inhabitants per km2) showing a clear increasing trend: e.g. the population density in the French coastal lands (a band of 10 km-wide) has continually increased during the most recent censuses: 111 inhabitants per km^2 in 1962, 126 in 1977, 134 in 1982 and 141 in 1990 (OSPAR Commission 2000).

Living marine resources exploited in the Bay of Biscay include a wide range of organisms, from seaweeds to molluscs and whales. Retrospective analyses on the human uses of the marine resources in the coastal margin of the Bay of Biscay have demonstrated the harvesting of gastropods and other intertidal animals since the Palaeolithic (17,000 BP) [e.g. long records on abundance of intertidal animals were provided by shells deposited in prehistoric middens (Ortea 1986)]. Whale hunting was a common practice all along the north Spanish coast from the Middle Ages (Figure 10-2) until its prohibition in the mid-1980s. Recent uses of marine resources include traditional fisheries of both pelagic and demersal species, and nearly 5000 French and Spanish boats are currently active in the Bay of Biscay. The coastal margin of the Bay of Biscay is also under considerable pressure from industrial activities known to cause pollution (paper milling, petroleum refining, iron and steel working, chemicals, etc.).

Descriptive aspects of the Bay of Biscay, both on the French and Spanish continental margins, have been extensively studied, and it is possible to recognise general patterns in circulation, annual cycles of planktonic communities, and distribution of demersal and pelagic fish populations. In spite of the effort devoted to the description of the assemblages of the marine communities, it is generally recognised that we do not know how species extend and contract their spatial distribution, nor how their abundance increases and decreases. This is due to the complexity of relationships among abiotic

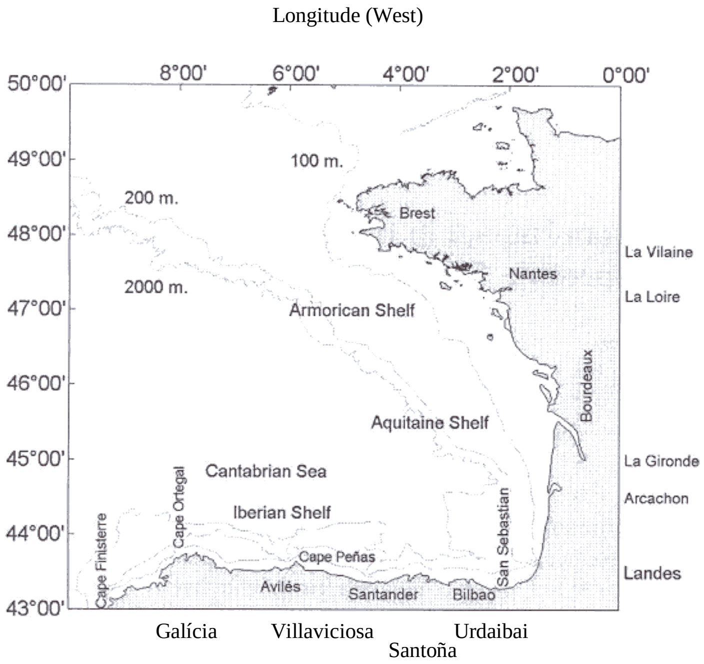


Figure 10-1. Map of the Bay of Biscay showing its main divisions and locations.

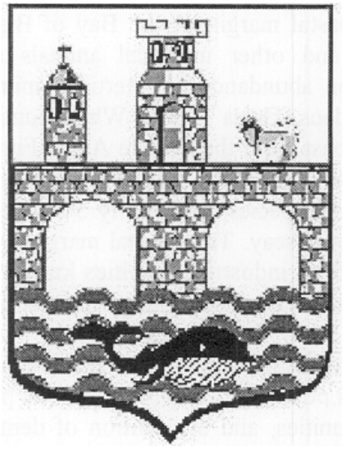


Figure 10-2. Middle Age crest of Ondarroa (North Spanish coast).

and biotic properties of the ecosystem, and because marine ecosystems are subject to different sources of variability (both natural and anthropogenic).

Natural variability occurs on a wide range of space and time scales and is inherent to the functioning of marine ecosystems. An ecosystem's variability over time is manifested through its seasonal, inter-annual, decadal, and centennial cycles. Spatial variability is associated with the vertical and horizontal movements of water Human impacts on ecosystems are many (fishing effects, marine litter, pollutants, etc.) and their effects on the ecosystem usually remain even when their original cause has disappeared. In addition, we should consider the impact of global warming, whose long-term impact on an ecosystem and its species remains unknown.

These cycles and sources of variability interact with the biological cycles of species, producing fluctuations in their abundance that are not always easy to explain and make it very difficult to determine the states of equilibrium of species d communities. The effects of pollution and global change on marine ecosystems are 9 nearly perceived by society only when these effects become evident at the upper end f the trophic system. Such effects include alterations in the abundance, distribution and diversity of fish and marine mammals but they also alter the equilibrium of invertebrates like limpets and echinoderms.

All the mentioned factors and our inability to detect emerging environmental problems at an early stage, when remedial measures are still possible, add a high degree of uncertainty to the proper management of marine resources and use of coastal areas, and in consequence, limit our capacity to plan a sustainable development policy for the coastal areas.

The present paper gives a description of the dynamics of the Bay of Biscay focusing in particular on the factors that are natural sources of variability and on the human activities that cause environmental degradation and alter the marine ecosystem. Some considerations for the scientific actions needed for better future management of marine living resources are discussed in the last section.

THE BAY OF BISCAY AS A LARGE MARINE ECOSYSTEM

Classical approaches to divide the World Ocean into regional ecosystems are based on the association of marine organisms that show a similar spatial distribution within geomorphological or ecological barriers that isolate them from floras and faunas of other areas (Golikov *et al.* 1990; Olson and Hood 1994). Parallel with the search for biogeographic patterns, new proposals have been made for an ecological geography of the oceans based on ecological criteria such as rates of critical physiological processes, physical forcing and plankton properties, timing in seasonal stages, features of the surface circulation, etc. (Nixon 1988; Legendre and Le Fevre 1991; Longhurst 1998). Finally, some recent attempts to classify the pelagic ecosystem into objectively defined geographic compartments include not only ecological criteria but also consider man as part of the ecosystem, interacting in many forms: exploiting resources, impacting the ecosystem, establishing management criteria, etc. Among these, the Large Marine Ecosystem approach (Sherman and Duda 1999) offers a comprehensive division of the coastal regions into 50 LME entities.

The Bay of Biscay lies in two different LMEs, though the scientific literature refers to this area as a single entity. This is supported by biogeographic patterns, comparative ecology and management criteria.

In terms of biogeography, the Bay of Biscay is a region of transition from subtropical to boreal regimes. Its most remarkable characteristic lies in its biological richness in floral and faunal species: at least 800 species of phytoplankton, more than 100 species of copepods, around 400 species of fish, 28 species of cetaceans, etc;, were identified in the region. Many species of seaweeds, invertebrates, fish and marine mammals reach into the Bay of Biscay as the southern or northern limits of their European continental margin distribution (Fischer-Piette 1955; Whitehead *et al.* 1984; Quéro *et al.* 1989; Sanchez *et al.* 1995). Good examples of the association of species in the Bay of Biscay are given by seaweeds: e.g. Bretagne and Galicia regions present species adapted to cold waters *(Laminaria saccharina, Himanthalia elongata,* and P*almaria palmata);* meanwhile, the inner Bay of Biscay presents species adapted to warmer conditions *(Gelidium sesquipedale, Gelidium latifolium* and *Corallina elongata).* Also, the spatial distribution of some commercial pelagic fishes like the mediterranean horse mackerel *(Trachurus mediterraneus)* and anchovy *(Engraulis encrasicholus)* is clearly restricted to the inner Bay of Biscay where they maintain a self-sustaining population; others such as sardine *(Sardina pilchardus)* extend the spatial distribution outside the Bay of Biscay, both to the north (Brest) and to the south-west (Galicia), but maintain main population of adults in both the Spanish and French margins of the bay. Migratory species such as mackerel *(Scomber scombrus)* arrive in the bay each year during the spawning season. Tagging experiments that monitor the migration routes have shown that mackerel stay in the Bay of Biscay until they commence the reverse migration to northern waters where the bulk of tags were recovered (Uriarte *et a.* 1998). Also, large pelagic fish such as bluefin tuna *(Thunnus thynnus)* and albacore (Th*unnus alalunga),* which live in subtropical areas of the western North Atlantic, make annual feeding migrations to the Bay of Biscay, reaching their maximum concentration in the bay during July and August when they are caught by the French and Spanish fleets. Thus, the Bay of Biscay maintains many different living species organised in both self- sustaining populations and seasonal/trophically dependent populations.

The recent review of Longhurst.(1998) on the comparative ecology of the sea divides the world oceans into four primary biomes which are subdivided into provinces. According to Longhurst, the North East Shelves Province can b split into primary divisions, one of them being the southern outer shelf from northern Spain to Ushant, including the Aquitaine and Armorican shelves off western France (i.e. the Bay of Biscay). This is supported by the characteristics of regional oceanography and by the

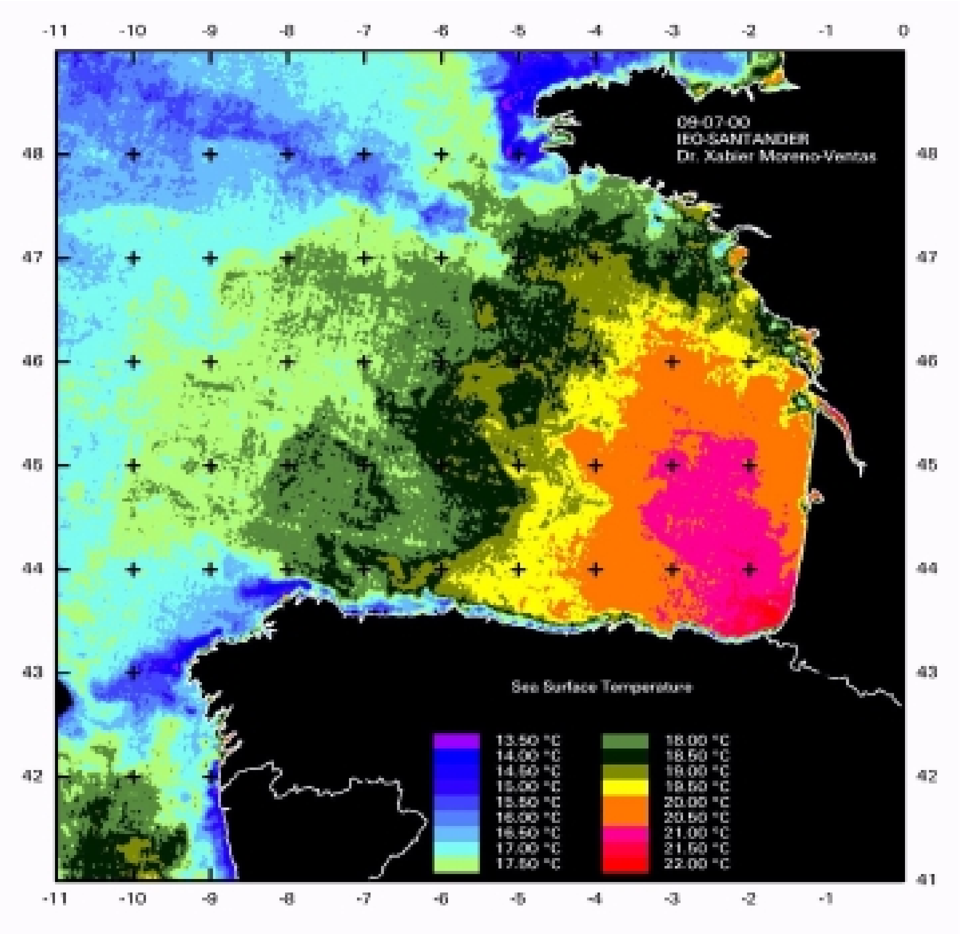


Figure 10-3. Temperature distribution (SST) of the Bay of Biscay (NE Atlantic) on July 7, 2000.

biological and ecological response to the regional environment. One of the most illustrative differences between the Bay of Biscay and the surrounding regions is given by the seasonal heating of surface waters from May to October that produces a shift in the distribution of the isotherms in the Bay of Biscay in such a way that a thermal discontinuity is created with the rest of the Atlantic (Figure 10-3). Because this thermal structure is maintained throughout the growth season, it has major implications for critical biological processes, to the extent that such a discontinuity corresponds with an ecological boundary. Other ecological aspects, such as physical forcing in relation to scales of temporal variability and the environmental risk induced by human activities, will be treated in detail in the following sections.

Management criteria regarding the Bay of Biscay include regulations on several fish species subject to Total Allowable Catches (TACs), such as anchovy, hake, blue whiting, etc. which are shared by France and Spain. Restrictions on catches are discussed in intemational commissions: ICES (Intemational Council for the Exploration of the Sea), STECF (Scientific, Technical and Economic Committee for Fisheries), etc. France and Spain also have a long history of scientific cooperation and promotion of regional research programmes for the Bay of Biscay (e.g. IEO-IFREMER Conference for the development of an integrated research of the Bay of Biscay ecosystem). Finally, France and Spain are signataries of several intemational conventions concerning conservation of natural environments comprising the Bay of Biscay .

The critical processes controlling the structure and functioning of biological communities, the stress and degradation on coastal spaces, and the exploitation of fish and other renewable resources, are the same at the regional scale of the whole Bay of Biscay, to the extent that the biological, ecological and management characteristics confirm that the Bay of Biscay is a well defined LME.

DYNAMICS OF THE BAY OF BISCAY MARINE ECOSYSTEM

The main scheme

The Bay of Biscay exhibits the ecological functioning of the temperate seas, whose dynamic is governed by climate and tides. Like the entire north-eastern Atlantic, this region undergoes a seasonal climatic cycle that strongly affects the pelagic ecosystem through three interrelated forcing factors over the year: sunlight exposure, heat input, and mechanical forcing on the surface due to wind. These forces produce a regular pattern in hydrographic conditions characterised by winter mixing of waters, followed by summer stratification. Phytoplankton blooms occur during the transition between both periods. The spring phytoplankton bloom, generally in March-early April, occurs when sunlight exposure is intense and long enough for net photosynthesis and is characterized by a dominance almost exclusively of diatoms (Casas *et al.* 1997). During summer stratification, nutrient concentration drops, phytoplankton biomass decreases to low levels and dinoflagellates are dominant. In winter, water mixing and low irradiance prevent phytoplankton growth in spite of high concentrations of nutrients.

The currents are governed by winds, tides, and density gradients. Wind-driven flow (Sverdrup circulation) induces the subpolar and subtropical gyres in the North Atlantic. The Bay of Biscay is located in the eastern part of these, influenced by the North Atlantic drift to the north and the Azores Current to the south. The currents induced by this general circulation are not very intense in the Bay of Biscay, and its being an oceanic bay further lessens their effects. Its geostrophic circulation is weak, being anticyclonic in the oceanic part (Saunders, 1982; Maillard, 1986) and cyclonic on the continental margin (Pingree, 1993) (Figure 10-4). Tidal currents have an oscillatory component (semi-diurnal) and a long-term component (residual current). The semi-diurnal component is greatest over the north-west Armorican shelf (about 0.5 m s^{-1}, locally reaching 1 m s^{-1}), decreasing towards the south along the Aquitaine shelf. It is not particularly intense over the Iberian shelf areas (10 cm s^{-1}). The residual component tends to be very weak (less than 1 cm s^{-1}) over most of the shelf. Locally, however, it may be one order of magnitude higher; this is the case near the islands of Noirmoutier, Oléron and Ré, on the inner Armorican shelf, where it can reach 10 cm s^{-1} and plays a major role in long-term transport.

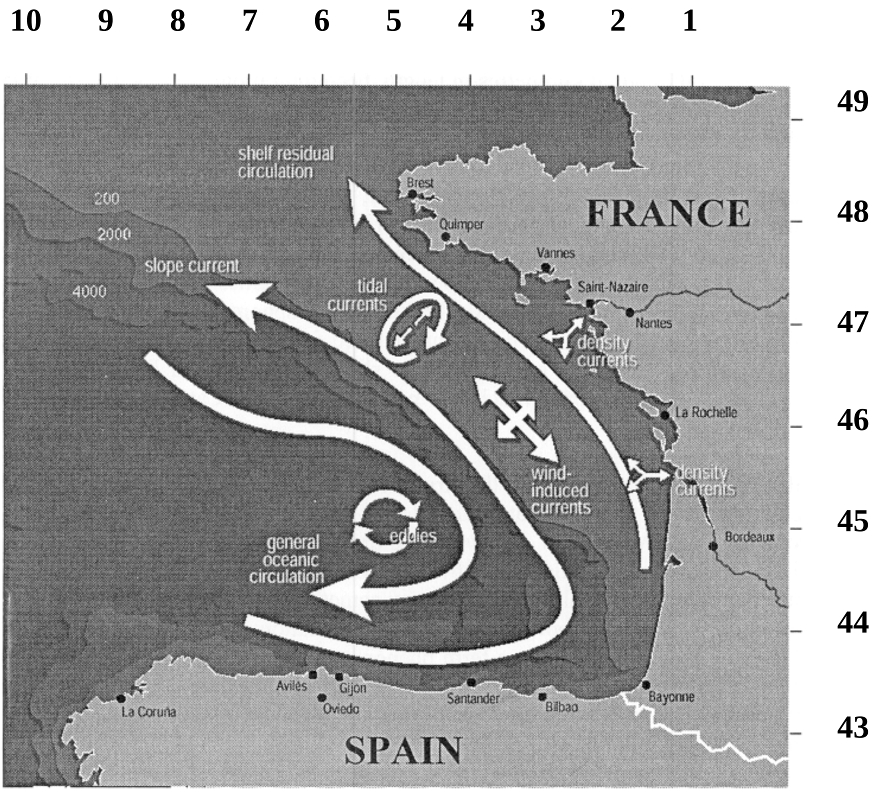


Figure 10-4. Circulation and currents in the Bay of Biscay (from Koutsikopoulos and Le Cann 1996).

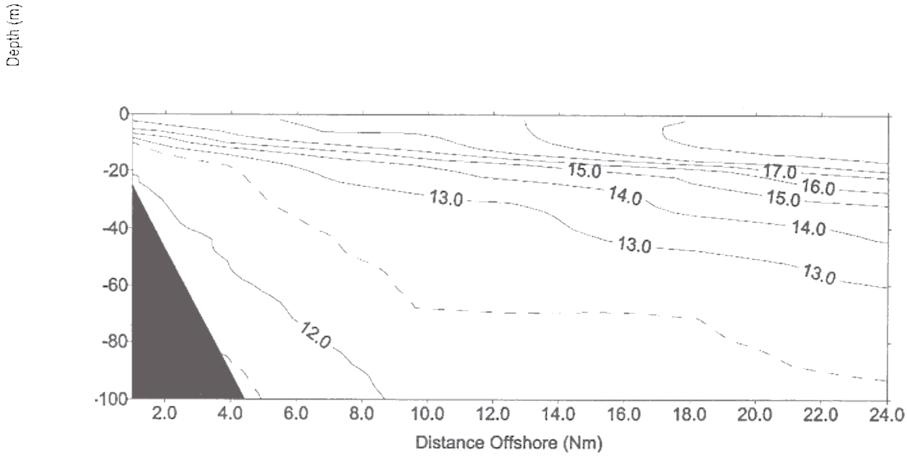
Seasonal variability in the vertical structure of coastal and oceanic waters

Both atmospheric events and internal waves modify the steady state of the water column by direct transfer of energy (e.g. wind stress and turbulence), flows of surface water with different properties (coastal run-off and river plumes), and modulation of the depth of the mixed layer.

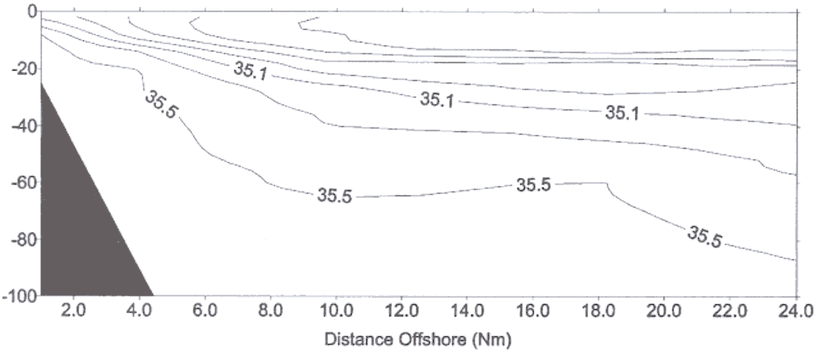
Coastal run-off and river plumes: The Gironde, the Loire and, to a lesser extent, the Vilaine Rivers provide large volumes of fresh water (which is turbid but rich in nutrients from the mainland) during spring. This results in the formation of dilution plumes at the surface of coastal waters, which drive significant northward currents over the inner Armorican shelf. They are clearly stratified vertically and delimited horizontally by a density front at the mouth of the estuary .Because the tidal currents along the Atlantic coast are much weaker than in the English Channel, these plumes can extend over several hundred kilometres in length, becoming progressively diffuse. With the continual input of nutrients they provide, these river plumes maintain very large 'new' phytoplankton production along the coastal fringe, and sometimes even to the edge of the continental shelf. Due to the haline stratification that maintains the phytoplankton cells in a very thin layer of water, phytoplankton production can start very early in the year. Triggering of this production could be favoured by an anticyclone regime, which is frequent in the region during winter (January to March). Studies have shown that these winter blooms linked to plumes from large rivers are relatively short, because they are quickly limited by phosphorous due to the high N/P ratios of river waters, which are highly unbalanced in favour of nitrogen. A lower volume of river run-off and a much narrower shelf off the Iberian Peninsula act in tandem to make buoyant plumes much less persistent over the Cantabrian coasts than over the Armorican shelf.

Internal waves and tidal fronts: At the Armorican shelf break, when the water column is vertically stratified, tides generate internal waves that propagate both on- and off- shelf from about 5° W to 9° W *(bourrelet froid).* Such internal waves appear to be responsible for significant mixing and upwelling of nutrients. Oscillations involving a sharp interface (e.g. a seasonal pycnocline) may sometimes produce surface signatures, as well as reinforce the barotropic current (due to oscillation of the ocean free surface) or act as forcing mechanisms of long-term phenomena (Sournia *et al.* 1990). This tidal front recurs annually, starting in June or July at the shelf-break where it has its maximum intensity and thus its greatest impact on primary production. Satellite images clearly show this phenomenon. Signs of upwelling on the front include an increase in fluorescence values, zooplanktonic biomass, and eggs and larvae of pelagic fishes, e.g. sardine, mackerel and horse-mackerel (Lago de Lanzós *et al.* 1997). The abundant, sustainable 'new' production makes this 100-km wide fringe, overhanging the continental shelf break, an oasis in the open sea and it is used by pelagic species as spawning grounds to nourish future larvae (Arbault and Boutin 1968; Lago de Lanzós *et al.* 1997).

TEMPERATURE



SALINITY



NITRATES

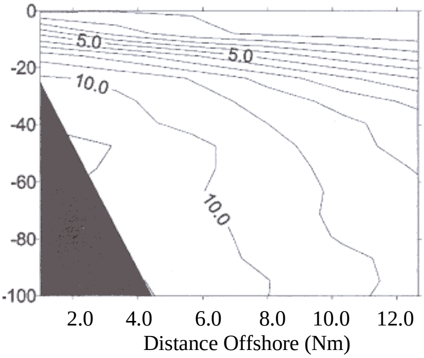


Figure 10-5. Cross-shelf section off Santander showing the signal of temperature, salinity and nitrates during an upwelling event (June 1995).

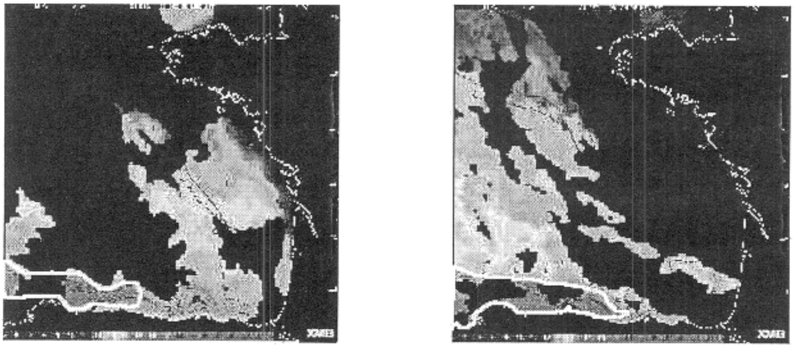
Interannual variability of mesoscale events

In the ocean, mesoscale motions are typically the most energetic physical processes; consequently, they represent major perturbations. Episodic mesoscale events are common in the Bay of Biscay, showing both high seasonal and inter-annual variability (Koutsikopoulos and Le Cann 1996). They have a dramatic impact on the ecosystem's productivity and in the transport of drifting biological material.

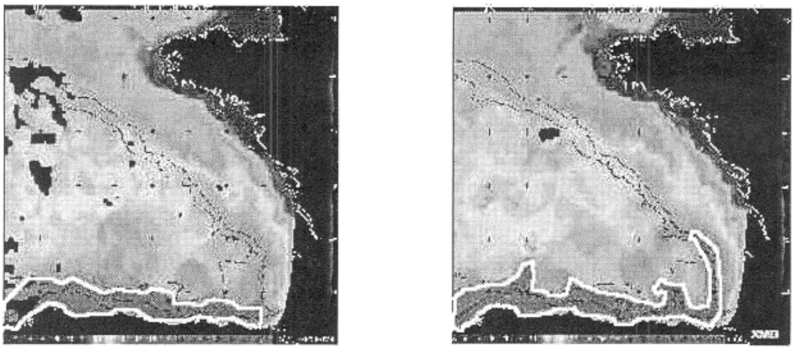
Coastal upwelling events occur on the Spanish and French continental margins. On the Spanish continental margin, upwelling extends from Galicia to the Cantabrian Sea (Molina 1972; Estrada 1982; Botas *et al.* 1990; Ríos *et al.* 1992; Lavín *et al.* 1998). Upwelling is more intense to the west of Cape Peñas and Ortegal, and acts as a mechanism generating spatial variability between the western and eastern zone of the Cantabrian Sea, and between the coastal mixed waters and the neighbouring oceanic stratified areas (Figure 10-5). Upwelling events are highly variable in intensity and frequency and they show a significant variability from year to year .When upwelling is particularly intense, surface signs of upwelling are observed first on the northern coast of Galicia, then off Asturias, and later to the east off Cantabria. On the French continental margin, mainly in summer, weak upwelling events are induced along the Landes coastline by northerly winds.

Navidad. Especially in winter, there is a warm and salty current (called *Navidad)* flowing from the central Atlantic and running from west to east along the slope of Spain' s northern coast, then flowing northward along the French continental slope (Frouin *et al.* 1990; Pingree 1994) (Figure 10-6). Mean velocities of 30 cm S-I were recorded at the shelf break in the central Cantabrian Sea during late December 1995 and January 1996 (Díaz del Río *et al.* 1996). Its influence on the area's biology has also been studied by Botas *et al.* (1988), Varela *et al.* (1998), Sánchez and Gil (2000), etc. Although the extent of intrusion is not a well-studied phenomenon, it seems to be more intense in the western zone of the Cantabrian Sea. These saline intrusions present a high space-time variability (Pingree and Le Cann 1990; Varela *et al.* 1995; Moreno-Ventas *et al.* 1997).

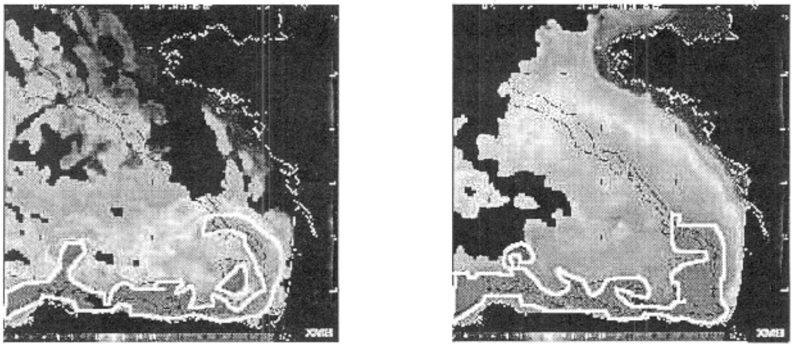
Slope Water Oceanic eDDIES (SWODDIES). Quasi-periodically (in some cases associated with the *Navidad* current, whose instability generates meanders that can break off in the form of free eddies) different anticyclonic and cyclonic eddies have been observed in the Bay of Biscay (Howe and Tait 1967; Pingree 1979; Dickson and Hughes 1981; Pingree and Le Cann 1992a; Moreno-Ventas *et al.* 1997). The formation of rings in the Bay of Biscay is frequent due to the currents' interaction with the topography of the continental margins (Pingree and Le Cann 1992a, b; Pingree 1994; Gil 1995). A set of regions with a high incidence of rings has been determined, such as the area between Cape Finisterre and Ortegal (Gil 1995; Porteiro *et al.* 1996; Díaz del Río *et al.* 1996) and the innermost part *(cul-de-sac)* of the bay (Pingree and Le Cann 1992a, b; Pingree 1994; Díaz del Río *et al.* 1996) (Figure 10-7). Although these structures, which have a diameter of approximately 100 km, move slowly (2 km d-1), some persist during more than one year, drifting over oceanic waters without



Dec 31-Jan 6 **24-30 Dec 95**



14-20 Jan 96 **7-13 Jan 96**



Jan 28- Feb 3 **21-27 Jan 96**

Figure 10-6. Weekly evolution of the poleward current (Navidad) from December 1995 to January 1996 in the Bay of Biscay. For illustration purposes the current is contoured by a white line on SST images (weekly average values) (from Moreno-Ventas *et al.* 1997).

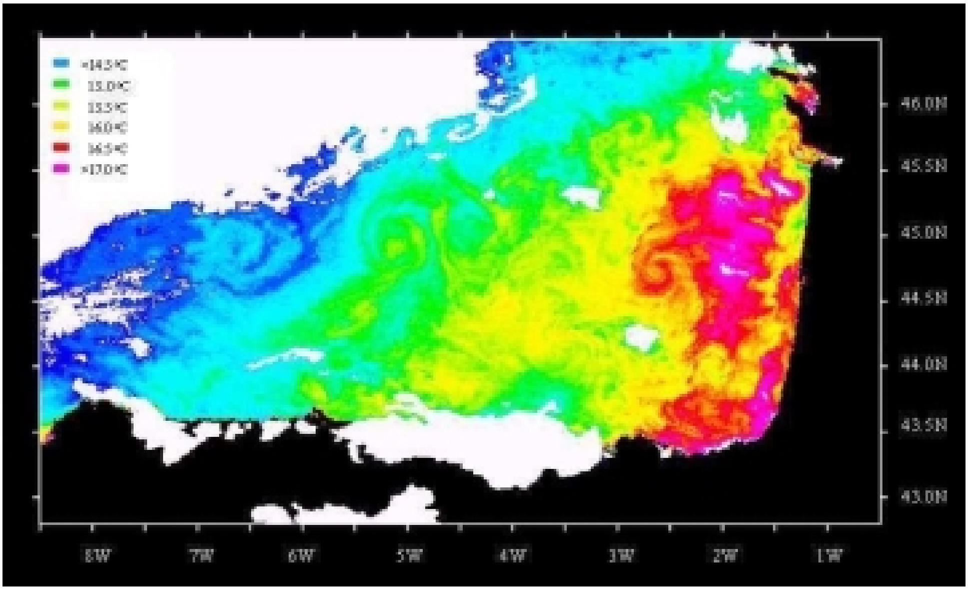


Figure 10-7. AVHRR satellite image showing the formation of eddies in the Bay of Biscay (24 May 1999).

necessarily being associated with the continental margin (Pingree and Le Cann 1992a). In summer, the persistence at the core of these eddies, between 10 and 300 m, brings, by hydrostatic effect, an uprising of isotherms (and therefore, f the thermocline) towards the surface. Due to their formation on the edge of the slope, these rings can trap and transport biological material from the shelf-break area, thus dispersing or accumulating populations (Porteiro *et al.* 1996).

Jet filaments and fronts. It is also necessary to consider fronts as elements that can disrupt the general pattern over the platform or along the shelf break. Fronts have diverse origins (e.g. upwelling filaments, instability of currents, anomalies associated with saline intrusions), but in any case they have great biologic interest, as well as playing an essential role as barriers to the transport of eggs and larvae. In many areas of the Atlantic, a close association has been found between spawning areas and shelf-break fronts (Iles and Sinclair 1985; Heath and MacLachlan 1987; Coombs *et al.* 1990). The success of pelagic fish recruitment depends to a great extent on whether spawning occurs in areas where larvae can find the proper prey in size and quality. Therefore, the presence of fronts during the period in which recruitment occurs can be decisive for the success of local fisheries.

Decadal variability al basin-scale

Climate and oceanic circulation interact in basin-scale water transport. Changes in heat fluxes on time-scales of one to several years can have a dramatic impact on standing stocks of plankton and higher trophic levels. The following oscillations have been shown to influence the Bay of Biscay.

NAO (North Atlantic Oscillation). The Bay of Biscay forms part of the eastern sector of the North Atlantic, and therefore it is in the area of influence of the periodic oscillations that act upon it. The most significant oscillation, with a periodicity of approximately 5-7 years, is the North Atlantic Oscillation (NAO) (Hurrell 1995). Related to the NAO, an increase in surface temperatures has been detected near Iceland, off Norway and in the North Sea (Dickson *et al.* 1988; Turrell *et al.* 1997). In the Bay of Biscay, a significant correlation ($P< 0.01$) has been found between the NAO index and the air temperatures measured in Santander by the INM (Instituto Nacional de Meteorología) for the historic series between 1961 and 1998 (Anon.1999).

Gulf Stream North Wall. The position of the Gulf Stream's north wall, where it separates from the American continental shelf, is a factor of great importance in climatic studies, since this current is responsible for the greatest heat transport in the Northern Hemisphere. The Gulf Stream latitude index (GULF) has been described by Taylor (1996), and was extrapolated from monthly charts of the latitude of the Gulf Stream's north wall at six longitudes, measured between 65° and 79º W for the period of 1966-1996. Applying a principal component analysis to the resulting correlation matrix, Taylor found a common pattern of variation at the six longitudes. The atmospheric displacement (changes in NAO index) seems to be able to induce (with an adjustment time) a displacement in the position of the Gulf Stream path. The adjustment time for oceanic circulation has been fixed at two years by Taylor and Stephens (1997) for the three decades studied.

Long-term trends

Accurate records of sea surface temperature in the Bay of Biscay are available for the whole century and data show an oscillatory pattern with first a rising period, from 1920 to 1960, when temperature increased in the order of half a degree; after that there was a phase of cooling which reversed in 1981 (Southward *et al.* 1995) and continues at present. Reasons that explain global warming include solar cycles like the 10-12 years sunspot cycle and the longer harmonics, the 30-40 years cycle in ocean-atmosphere interactions (Stocker 1994), and the greenhouse effect. However, in terms of solar cycle and orbital momentum, the earth is entering into a cooler phase, thus the climatic basis of global warming is not clear and it is suggested that the most recent warming represents the greenhouse effect superimposed on a natural cooling (Southward *et al.* 1995), which remark the importance of the human impact on climate. Modellers (e.g.

Stouffer *el al.* 1994) think that the signal of global warming is stronger than any stochastic variation.

In the Southern Bay of Biscay a warming trend is currently detected down to a depth of 75 m on the shelf and oceanic waters (Lavín *et al.* 1998). The same authors have estimated that in the period 1991-1999 the temperature at 10 m had risen 0.5 °C in the Southern Bay of Biscay (annual rate of 0.06 °C, Figure 10-8). A similar rise was reported off San Sebastián between 1986 and 1990 by Valencia (1993), and throughout the Bay of Biscay by Koutsikopoulos *et al.* (1998). This atmospheric and surface-water warming could have severe consequences for the ecology of the ecosystem. Lavín *et al.* (1998) noted that the water column experienced a higher degree of stratification, which also remained stratified for a longer period of time. Valdés and Moral (1998) have related this higher degree of water-column stratification to a less intense exchange of nutrients with the surface layers, which in the end means a reinforcement of the microbial loop, a decrease in the mesozooplankton biomass, a drop in the number of species per unit of volume, and a shift of the classic trophic chain to a less efficient one.

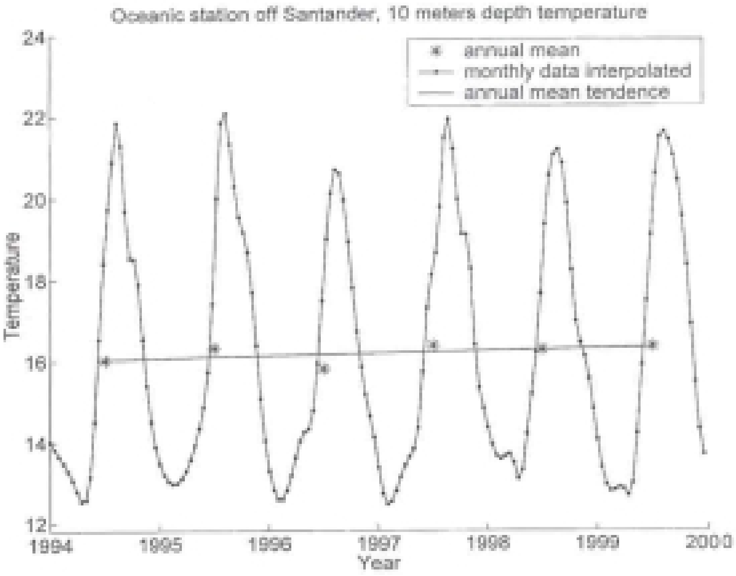


Figure 10-8. Time series mean temperature at 10 m depth off Santander in the period 1991-1999. Linear trend shows an increase in annual mean temperature of 0.06 °C.

HUMAN IMPACT IN THE BAY OF BISCAY

The Bay of Biscay has experienced dramatic changes in the coastal use of land and living resources during the last 50 years. Fast growth of population and socioeconomic development have resulted in environmental imbalances; but information and data are scarce, often restricted to inner coastal areas and usually produced by local agencies that strongly limit the access to data and its accuracy. Thus, it is difficult to: i) determine the full range of human impacts in the Bay of Biscay, ii) evaluate the environmental importance and the economic cost of man's uses of the marine ecosystem, and iii) establish social and administrative priorities addressed to rational management and sustainable use of the resources. In the absence of a quantitative scale of the importance of human 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, and transport, building and maintenance of infrastructures). In general, the disturbances produced by man can be stated as inputs of specific substances, physical disturbances and direct impacts on biological communities and species.

Human settlements on the coast in the last century have resulted in large populations, with all the problems associated with urban agglomerations. Tourism, new urbanisation of coastal areas and recreational uses of beaches and shores have added pressure, including the disposals of by-products of human sewage. Ecological disturbances produced by human settlements include microbiological pollution, eutrophication, land reclamation, loss of habitats and marine litter. Estuaries and coastal lagoons receive the main impact of microbiological contamination from urban origin, which has a strong impact on the quality of bathing waters and shellfish salubrity .The implementation of recent Directives from the EU on water treatment and depuration will result in a diminishing of this kind of risk in the near future. Most of the data on floating debris or litter along the coast (particularly on beaches) refers to glass, plastics, metal, paper, bottles, clothing, foodstuff, wood, rubber, packaging materials, rest of trawl and other fishing gear. In general, plastics constitute about 85% of the accumulations because of their poor degradability .Plastics enter the marine environment as discards by recreational users of beaches, and from ships, sewers and coastal runoff. Although 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 been described.

Extractive activities include fishing, aquaculture and fanning. The ecological disturbances include direct impact on target species, overfishing, alterations on the seabed, introduction of non-indigenous species, agriculture sewages, etc. The Bay of Biscay has traditionally been an area of intense fishing activity and nearly 5000 fishing boats operate there. Trawlers and purse seiners are the main fishing vessels used for demersal and pelagic species. Other gears used to a lesser extent are gill nets, lines, dragnets, etc. Fishing activities not only affect the pelagic and demersal fish species.

Many intertidal populations are also subject to exploitation: clams, crabs, octopus and others, including the sea urchin *Paracentrotus lividus*, which is intensively exploited on the north coast of Spain and whose intertidal population has virtually disappeared from wide areas (this species is now restricted to tide pools and made up of small-sized individuals). The aquaculture industry has increased greatly in the last decade and environmental risks associated with this activity are under debate. Society has recently been made aware of the use of GMOs (Genetically Modified Organisms), but the use of such organisms has not yet been reported in the Bay of Biscay.

Since the 1970s the use of DDT in agriculture has been banned in most countries. Nevertheless, residues of DDT and in particular its metabolites, DDE and DDD, are found in the environment in suspended material, sediments and biota; the main places for accumulation are rias, estuaries and coastal lagoons. The inputs usually occur during the run-off periods (Ferreira and Vale 1995). Agriculture is also the primary source of nutrients carried to the coastal water by the rivers.

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, e.g. paper milling, petroleum refining, iron and steel working, chemicals, etc. Disturbances of the ecosystem include industrial discharges and inputs of specific pollutants (both inorganic and organic compounds). Mercury is associated with papermill industries and is recognised as one of the most important inorganic pollutants. PAHs (Policyclic Aromatic Hydrocarbons) can occur naturally but their concentrations may increase significantly due to human activities: incomplete combustion, marine oil extraction, industrial discharge, oil traffic and handling, etc. Petrochemicals are one of the most significant human-induced problems of contamination.

Transport, building and maintenance of infrastructures include activities such as coastal protection, land reclamation, dredging, and shipping. Sediments are often dredged in harbour areas, estuaries, and navigation channels. The material excavated 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 to new projects for harbour development requiring capital dredging. On the French coastal and estuarine areas of the Bay of Biscay, the annual quantity of dredged and dumped material represented roughly 106 m3 in 1993, about one percent of this amount being composed of contaminated sediments. The dumping of material produced by maintenance dredging of ports and navigation channels has a potential temporary and long term impact on the bottom and water column of the dump site because of the scale of the dumping and the general contaminated nature of the sediments. The highest levels of contaminants in water, sediments and biota were found in coastal areas, mainly in estuaries, rias and semi-enclosed sites, due to slow water renewal and to higher urban and industrial concentrations. Shipping accidents can produce unintentional pollution; in December 1999 the supertanker *Erika* wrecked on the coast of France and 10,000 tons of oil were spilled in shallow waters. Due to the strong wind in the area, the "black tide" moved to the coast and large expanses of French beaches were contaminated by oil.

EFFECTS OF THE ECOSYSTEM VARIABILITY AND HUMAN IMPACT ON SPECIES AND HABITATS OF THE BAY OF BISCAY

The ecosystem dynamics and human impacts mentioned in the preceding sections interact with the biological cycles of the species, producing fluctuations in their abundance which are not always easy to explain. At high trophic levels our perception of the states of equilibrium of species and communities is even worse because, depending on the biology of the species (e.g. short/long life), natural and anthropogenic variabilities have an impact on future generations. This means that though fluctuations are more common and sharper in short-lived species, they are more persistent over time in those species for which various cohorts co-exist simultaneously in the ecosystem.

lnteractions between environmental variability and population dynamics

Small pelagic fishes of commercial value, such as sardine *(Sardina pilchardus)* and anchovy *(Engraulis encrasicolus),* are highly dependent on environmental conditions. The distribution of sardine extends outside the Bay of Biscay, both to the north (Brest) and to the south-west (Galicia). The sardine, like other clupeids, is a relatively short-lived species at the base of the food chain, and is subject to a very high rate of natural mortality .The variability in annual recruitment leads quickly to changes in population abundance, and consequently affects the fishery's productivity. Sardine catches in the Bay of Biscay have diminished in recent years and the species is under biological regulations. Sardine recruitment has been related to the frequency and intensity of upwelling events (Robles *et al.* 1992; Roy 1993; Cabanas and Porteiro 1998). According to Roy (1993), sardine adapts its spawning strategy to upwelling, taking advantage of an environmental window of opportunity to optimise larval survival. Below a certain level of upwelling intensity, survival falls; and above a certain intensity threshold, eggs and larvae are advected towards the ocean, where they are lost to the population.

Sardine recruitment has also been correlated with air temperature (Figure 10-9) (Lavín *et al.* 1997; Cabanas and Porteiro 1998). Sea surface temperature in coastal waters of the southern Bay of Biscay has increased in recent years (Lavín *et al.* 1998). This suggests that the observed rise in temperature reported in these waters has produced an increase in the thermal stratification of the water column. A linear decreasing relationship between water-column stratification and the number of copepod species has been observed in the shelf waters of the southern Bay of Biscay during the period 1991-1996 (Valdés and Moral 1998). Roemmich and McGowan (1995), Southward and Boalch (1994) and Southward *et al.* (1995) also suggest that a warming trend is related to zooplankton decay in the Pacific and in the English Channel, due to a reduction in nutrient supply to the photic layers and to the predominance of microflagellates in the plankton. Thus, the relationship between air temperature and sardine recruitment may be explained by a cascade relationship between water-column stratification and low food availability during warm years. Consequently, when searching for factors forcing the sardine population, we have to take into account not only local conditions, but also those climate changes that are occurring at a basin or global scale.

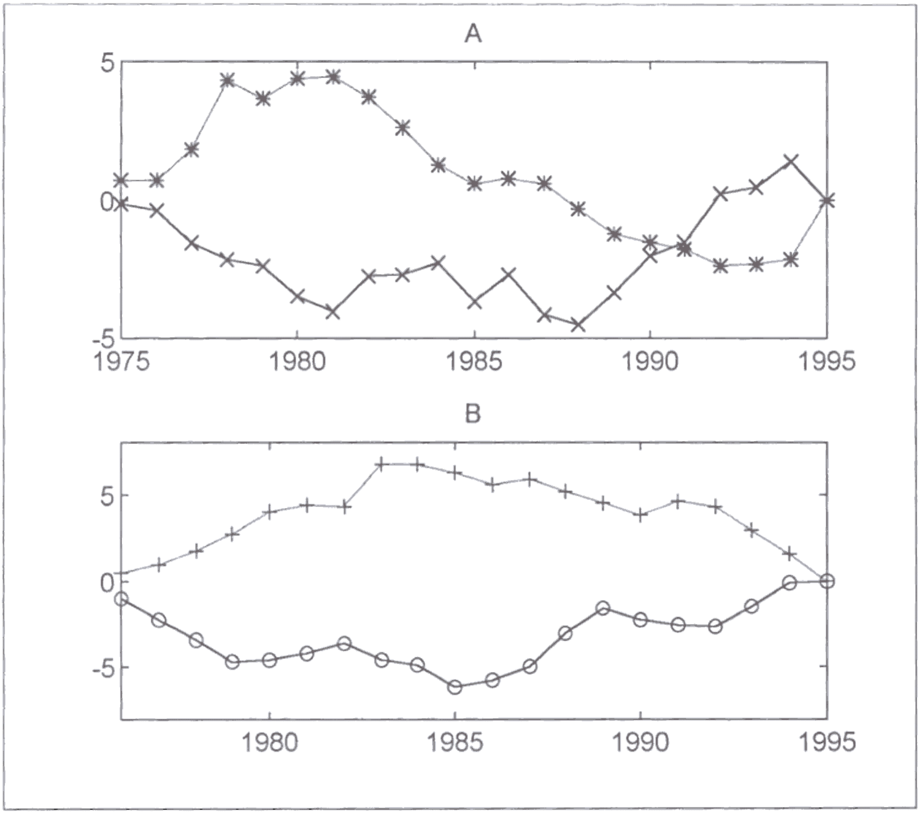


Figure 10-9. (A) Cumulative sum of anomalies of NAO (X) and albacore recruitment (*) between 1976 and 1995. (B) Cumulative sum of anomalies of air temperature (o) and sardine recruitment (+) between 1976 and 1995 (Lavín *et al.* 1997).

The anchovy is the only pelagic species whose principal population is confined to the Bay of Biscay. The Bay of Biscay anchovy shows dramatic inter-annual recruitment fluctuations that make it difficult to offer scientific advice for the management of the fishery. The species shows a strong connection between its spawning habits and recruitment success and oceanographic features such as coastal run-off, shelf-break fronts and eddies (Motos *et al.* 1996). Recruitment is influenced by the wind regime and Borja *et al.* (1996) found a clear relationship between anchovy recruitment intensity and upwelling intensity on the French and Spanish coast. Junquera (1988) has also suggested a relationship between anchovy recruitment and global warming.

Oceanic pelagic species of tuna found in the Bay of Biscay are the albacore, Th*unnus alalunga,* and the bluefin, Th*unnus thynnus.* Both show oscillations in their abundance and distribution in response to basin-scale shifts in the North Atlantic oceanic current system. The NAO and GULF indices provide a connection between northward displacement of the Gulf Stream current and tuna distribution. Both albacore and bluefin tuna are present in this area from the beginning of spring to mid-autumn, depending on oceanographic conditions, especially temperature. These two species live in subtropical areas of the western Atlantic and make annual feeding migrations to the Bay of Biscay. Tuna schools begin to move in an easterly direction at the beginning of spring, and reach their maximum concentration in the Bay of Biscay during July and August, when they are caught by the French and Spanish fleets. The albacore tuna population present in this area is comprised of juveniles (1-4 years) from the northern Atlantic stock. The annual catches are on the order of 16,000 t in the Bay of Biscay and north-east Atlantic (average data from 1993-1997), with a maximum of 40,000 t in 1960 when baitboat and troll fleets from France and Spain were targeting this species. The bluefin population is also made up, in part, of juveniles from the eastern Atlantic stock.

Cyclical oscillations, such as the NAO, have been related to fluctuations in abundance of albacore and bluefin tuna (Ortiz de Zárate *et al.* 1997; Santiago 1997). Results suggest that during periods of high NAO, when the westerly winds intensify, the recruitment of albacore is low (Figure 10-9). Increased turbulence due to these strong winds could have a negative impact on recruitment. During periods of low NAO, convective activity in the Sargasso Sea is high (Dickson *et al.* 1996), which may provide good recruitment conditions. Bluefin shows opposite patterns to those shown by albacore. With regard to aggregated immature catches of albacore (ages 2 and 3) of the northern stock, correlation is significant and negative with the index of Gulf Stream latitude and mean sea level. These two factors may provide an idea of the influence of the North Atlantic Current on young albacore. The northward displacement of the current could bring these tuna out of the fisheries area.

Environmental risks due to human activities

Fisheries have severe impacts on the ecosystem. Direct impacts include effects on the target species: increase in the mortality rate, reduction of average age and size, and decrease of the fecundity rate, which can result in a depletion of the spawning stock to a level where the sustainability of the resource is threatened. This is particularly the case for species with late maturity and low fecundity. Examples of such impacts on marine fish populations have been reported for *Raja clavata* and *Scyliorhinus canicula* (Quero and Cendrero 1996; Sánchez *et al.* 1997), which have been proposed as key species to monitor changes in marine exploited systems. Post escapement mortality, discards and lost gear also directly affect target and non-target species. Indirect effects on the ecosystem include disturbances of the seabed with impact on benthic communities, by-catches of cetaceans and seabirds, changes in species assemblages and their relative abundances, i.e. reduction in diversity through the elimination of the specialist species with low birth rates, alteration of the natural equilibrium between predator and prey species, etc. (OSPAR Commission 2000).

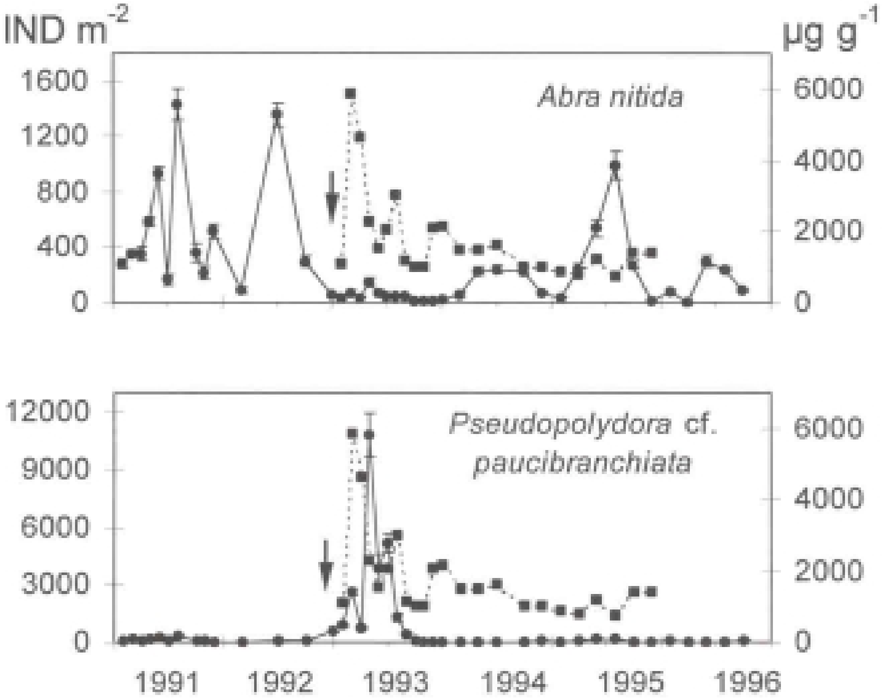


Figure 10-10. Decrease in the abundance of the species *Abra nitida* (upper panel, solid line) and colonisation of substrata by the opportunistic species *Pseudopolydora cf paucibranchiata* (lower panel, solid line) after the *Aegean Sea* oil spill (dashed lines show oil concentration in sediment, arrows refer to oil spill) (Parra and López-Jamar 1997).

Benthic communities are very sensitive to changes in water properties and human impacts. One example is the toxic effects of the oil from the supertanker "Aegean Sea" (wrecked in La Coruña in 1992), which caused a temporal reduction of the macroinfauna (amphipods, echinoderms, molluscs) with a simultaneous dramatic increase of opportunist polychaetes (mainly P*seudopolydora aucibranchiata* and *Capitella capitata)* (Parra and López-Jamar 1997) (Figure 10-10). Although the immediate effects of the contamination were dramatic, the abundance and diversity of the meiofauna recovered after three years.

Other impacts on benthic or organism are due to industrial activities and industrial waste. which have led to some alterations in macroalgal assemblages at specific locations; and urban sewage, which increases the level of nutrients and enhance the proliferation of green algae, e.g. *Ulva* and *Monostroma.* Most of these alterations in the Bay of Biscay take the appearance of local imbalances rather than serious alterations in the ecosystem. Solid waste has become a new form of pollution by the generalised use of plastic. A risk of the impact on cetaceans from marine litter, mainly plastic bags d other debris, was recently reported. In one case, mo e than 50 kg of plastics were found in the stomach content of a fin whale *(Balaneoptera physalus)* stranded on a beach in Cantabria in November 1997 (García-Castrillo 1998). Also, between 1988 an 1998, plastics were found in the stomach contents of sea turtles *(Dermochelys coriacea)* in 22 of 43 autopsies recorded (Duguy *et al.* 1998). Other causes of mortality resenting a real risk to marine mammal species have arisen, such as ship collisions, noise, anthropogenic disease agents, fishing gear, etc.

Other human activities that cause environmental degradation an local imbalances in the Bay of Biscay include shipping, microbiological pollution, eutrophication, marine litter, and contaminants. TBT has been reported to produce shell calcification anomalies in adult oysters, and declining reproduction in the Bay of Arcachon .TBT also alters the physiology of dogwhelks *Nucella lapillus,* wherein females develop male sexual characteristics. It can also cause sterility and have destructive effects on the population, as reported from industrial bays and some estuaries of NW Spain (OSPAR Commission 2000).

Finally, during the last decades there have been new appearances f introduced species in the coastal areas. The entrance vectors of these alien species are both natural (e.g. transported by currents) and human induced, caused by intensification of communications and shipping, travel in ballast water on commercial vessels or adherence to a ship's keel and hull, or transfer of shellfish. The introduction of non- indigenous species carries the risk of introducing pests and disease, and establishing undesirable ecological effects in relation to existing species. samples of species introduced in the Bay of Biscay include seaweeds (~.g. *Undaria pinnatifida*, which escaped from farms and disseminated in the natural environment, where it carries out its entire cycle), molluscs (e.g. *Crassostrea gigas* and *Crepidula fornicata),* and crustaceans *(Hemigrapsus penicillatus* and *Elminius modestus).*

Overlapping all these fluctuatio9s and human impacts, there are global climatic processes that affect large areas and influence all populations. These changes tend to operate slowly and can affect: i) the behaviour of species (e.g. changes in migratory routes), ii) their recruitment (due to changes in the environmental conditions in the spawning and/or recruitment areas), and iii) the spatial distribution of species. Generally, these changes mark long-term population trends.

Southward and Boalch (1994) and Southward *et al.* (1995) suggest that if the predicted global warming results in increases in temperature on the order of 2 °C, then there will be considerable changes in marine communities, producing latitudinal shifts in species distribution on the order of 200-400 miles, especially for mobile animals such as fish. In fact, the warming trend seems to be responsible for the appearance of tropical fish species on the south-east shelf of the Bay of Biscay. Several tropical species *(Cyttopsis roseus, Zenopsis conchifer* and *Sphoeroides pachygaster)* have been caught throughout the Portuguese, Spanish and French Atlantic margin (Quéro *et al.* 1997, 1998). The subtropical copepod *Temora stylifera* has also shown a significant increasing trend during the last 15 years in the Bay of Biscay (Villate *et al.* 1997). Sessile intertidal organisms such as limpets and barnacles were also reported to show changes in their spatial distribution towards northern areas (Southward *et al.* 1995).

In addition to the impact of human activities on communities and species, there is also an impact on the different types of coastal habitats. Among the coastal habitats (estuaries, coastal lagoons, rocky cliffs, shingles, rocky shores, sandy and muddy shores), estuaries are among the most productive and dynamic coastal ecosystems because of their role in the transformation and transfer of materials from the land to the sea. The main physical disturbance in the Bay of Biscay is the loss of estuarine habitats -mainly wetlands, saltmarshes and dunes- caused by land reclamation, sand extraction, agriculture, and aquaculture. Moreover, the sediments accumulate many organic and inorganic pollutants from mines, farms and industries. The most heavily polluted of such areas are the relatively small rías of Avilés and Bilbao. Depending on the season, eutrophication is also considerable in Arcachon (OSPAR Commission 2000).

Estuaries are subject to intense human pressure and are also the area most vulnerable to sea level rise due to global warming. Thus, they are the areas of greatest importance for conservation. The large estuaries of the Gironde and Loire (France) are important areas to protect, as are many marshes of the Spanish northern estuaries, such as those of Villaviciosa, Santoña and Urdaibai, which are important in terms of conservation (these are the most important migratory passes of waders and wintering areas for birds in the north of Spain). Other areas of importance for conservation coincide with the main seabird breeding colonies.

CONCLUDING COMMENTS

The above discussion indicates that we have a certain level of knowledge regarding the time-space variability factors regulating the fluctuations of biological communities. However, we still do not understand the connections between biological and physical processes, the parameterisation of flows, or possible cascade transmissions of variability. In other words, we do not know how the ecosystem is regulated. This lack of knowledge is evidence of the great need for more studies on ecosystem functioning in the Bay of Biscay. I

It is also evident that all the pressing environmental problems caused by man's activities and the complexity of ecosystem interactions add a high degree of uncertainty to the proper management of living marine resources and uses of coastal areas; and it makes imperative that the future management of marine living resources be based on a more solid basis of scientific knowledge. Integration of disciplines is necessary to provide comprehensive answers to the central issues of ecosystem management from an holistic approach. Time series programmes on adequate spatial and time scales supported by governmental agencies should be encouraged. There is also a need for improved forecasting of human impacts on the ecosystem. Future integrative projects should give increased attention to the human role in the regulation of the marine ecosystem. Searching for changing trends based on key species, and monitoring the preservation state of selected areas should also be a major priority.

REFERENCES

Anon. 1998. Priorisation of human pressures for the Greater North Sea Quality Status Report 1999. An interactive and iterative Multi Criteria Analyses approach. Results and methodology. Delft, RA/98-33l, December 1998.

Anon. 1999. Report of the ICES Working Group on Oceanic Hydrography. ICES CM 1999/C: 8.

Arbault, S. and N. Boutin. 1968. Ichtyoplancton. Oeufs et larves de poissons téléostéens dans le Golfe de Gascogne en 1964. Revue des Travaux Institut Scientifique et Technique des Peches Maritimes, 32(4): 413-476.

Borja, A., A. Uriarte, v. Valencia, L. Motos, and Ad. Uriarte 1996. Relationship between anchovy *(Engraulis encrasicolus* L.) recruitment and the environment in the Bay of Biscay. Scientia Marina, 60 (2): 179-192.

Botas, J.A., A. Bode, E. Fernández, and R. Anadón. 1988. Descripción de una intrusión de agua de elevada salinidad en el Cantábrico central: distribución de los nutrientes inorgánicos y su relación con el fitoplancton. Investigación Pesquera, 52 (4): 561-574.

Botas, J.A., E. Fernández, A. Bode, and R. Anadón. 1990. A persistent upwelling off the Central Cantabrian Coast (Bay of Biscay). Estuarine , Coastal and Shelf Science, 30: 185-199.

Cabanas, J.M. and C. Porteiro. 1998. Links between the North Atlantic Sardine recruitment and their environment. ICES CM 1998/R: 23.

Casas, B., M. Varela, M. Canle, N. González, and A. Bode. 1997. Seasonal variations of nutrients, seston and phytoplankton, and upwelling intensity, off La Coruña (NW Spain). Estuarine, Coastal and Shelf Science, 44: 767-778.

Coombs, S.H., J. Aiken, and T.D. Griffin. 1990. The aetiology of mackerel spawning to the west of the British Isles. Meeresforschung, 33: 52-75.

Díaz del Río, G., A. Lavín, J. Alonso, J.M. Cabanas, and x. Moreno-Ventas. 1996. Hydrographic variability in Bay of Biscay shelf and slope waters in spring 1994, 1995, 1996 and relation to biological drifting material. ICES CM 1996/S: 18.

Dickson, R.R. and D.A. Hughes. 1981. Satellite evidence of mesoscale eddy activity over the Biscay abyssal plain. Oceanologica Acta, 4: 43-46.

Dickson, R.R., P.M. Kelly, J.M. Colebrook, W.S. Wooster, and D.H. Cushing. 1988. North winds and production in the eastern North Atlantic. Journal of Plankton Research, 10(1): 151-169.

Dickson, R.R., J. Lazier, J. Meincke, P. Rhines, and J. Swift. 1996. Long-term coordinated changes in the convective activity of the North Atlantic. Progress in Oceanography, 38: 241-295.

Duguy, R., P. Moriniene, and C. Le Milinaire. 1998. Facteurs de mortalité observés chez les tortues marines dans le Golfe de Gascogne. Oceanologica Acta, 21(2): 383-388.

Estrada, M. 1982. Ciclo anual del fitoplancton en la zona costera frente a Punta Endata (Golfo de Vizcaya). Investigación Pesquera, 46(3): 469- 491.

Ferreira, A.M. and C. Vale. 1995. The importance of runoff to DDT and PCB inputs to the Sado estuary and Ría Formosa. Netherland Journal of Aquatic Ecology, 29 (3-4): 211-216.

Fischer-Piette, E. 1955. Sur les déplacements des frontiers biogeographiques intercotidales observables en Espagne: situation en 1954-55i. Comptes Rendus. Academie des Sciences (Paris), 241: 447-449.

Frouin, R., A.F.G. Fiuza, I. Ambar, and T.J. Boyd. 1990. Observations of a poleward surface current off the coasts of Portugal and Spain during winter. Journal of Geophysical Research, 95 (C1): 679- 691.

García-Castrillo, G. 1998. Informe sobre la ballena (Balaneoptera physalus) de Oriñon. Informe Interno Consejería de Cultura y Deporte, Gobierno de Cantabria.

Gil, J. 1995. Inestabilidades, fenómenos de mesoescala y movimiento vertical a lo largo del borde sur del Golfo de Vizcaya. Boletín Instituto Español de Oceanografía, 11(2): 141-159.

Golikov, A.N., M.A. Dolgolemko, N.V. Maximovich, and O.A. Scarlato. 1990. Theoretical approaches to marine biogeography. Marine Ecology Progress Series, 63: 289-301.

Heath, M.R. and P. MacLacWan. 1987. Dispersion and mortality of yolk-sac herring (Clupea harengus L.) larvae from a spawning ground to the west of the Outer Hebrides. Journal of Plankton Research, 9: 613-630.

Howe, M.R. and R.I. Tait. 1967. A subsurface cold core eddy. Deep-Sea Research, 33: 383- 404.

Hurrell, J.W. 1995. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science, 269: 676-679.

Iles, T.D., and M. Sinclair. 1985. An instance of herring larval retention in the North Sea. ICES CM 1985/H: 43.

Junquera, S. 1988. Changes in the anchovy fishery of the Bay of Biscay in relation to climatic and Oceanographic variations in the North Atlantic. Symposium on Long-term Changes of Marine Fish Populations, Vigo 1986: 543-554.

Koutsikopoulos C. and B. Le Cann. 1996. Physical process s and hydrological structures related to the Bay of Biscay anchovy. Scientia Marina, 60(2): 9-19.

Koutsikopoulos C., P. Beillois, C. Leroy, and F. Taillefer. 1998. Temporal trends and spatial structures of the Sea Surface Temperature in the Bay of Biscay. Oceanologica Acta, 21(2): 335-344.

Lago de Lanzós, A., L. Valdés, C. Franco, A. Solá, and X. More -Ventas. 1997. Bay of Biscay environmental scenary in June and distribution of early fish stages. Plankton Symposium. Galway, Ireland.

Lavín, A., L. Valdés, X. Moreno-Ventas, V. Ortiz de Zárate, and C. Porteiro. 1997. Common signals between physical, atmospheric variables, North Iberian sardine recruitment and North Atlantic albacore recruitment. ICES/GLOBEC Workshop on Prediction and Decadal-scale Fluctuations on the North Atlantic. Copenhagen. Sept 1997.

Lavín, A., L. Va1dés, J. Gil, and M. Mora1. 1998. Seasonal and inter-annual variability in properties of surface water off Santander (Bay of Biscay) (1991-1995). Oceanologica Acta, 21 (2): 179-190.

Legendre, L. and J. Le Févre. 1991. From individual plankton cells to pelagic marine ecosystems and to global biogeochemical cycles. In S. Demers, ed. Particle analysis in Oceanography. NATO ASI Series, G 27: 261-300.1

Longhurst, A. 1998. Ecological geography of the Sea. Academic Press, San Diego. 398 p.

Maillard, C. 1986. Atlas Hydrologique de l' Atlantique Nord-Est. IFREMER. Brest. 260 p.

Molina, R. 1972. Contribución al estudio del upwelling frente a la costa nordoccidental de la Peninsula Ibérica. Boletín Instituto Español de Oceanografia, 152.

Moreno-Ventas, X., A. Lavín, and L. Valdés. 1997. Hydrodynamic Singularities Observed by Satellite Imagery in the Continental Margin of the Bay of Biscay. 2° Simposium Intemacional sobre el Margen Continental lbérico Atlántico. Cádiz, Spain.

Motos L., A. Uriarte, and V. Valencia. 1996. The spawning environment of the Bay of Biscay anchovy (Engraulis encrasicolus L.). Scientia Marina 60 (2): 117-140.

Nixon, S. W .1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnology and Oceanography, 33(4, partI2): 1005-1025

Olson, D.O. and R.R. Hood. 1994. Modelling pelagic biogeography. Progress in Oceanography,34: 161-205.

Ortea, J. 1986. The malacology of La Riera Cave. Arizona State University Anthropological Research Papers, 36: 289-298.

Ortiz de Zárate, V. , A. Lavín, and X. Moreno- Ventas. 1997. Is there a relationship between environmental variables and the surface catch of albacore Thunnus alalunga (Bonnaterre, 1788) in the North Atlantic? SCRS/97 /54.

OSPAR Commission. 2000. Quality Status Report 2000: Region IV : Bay of Biscay and Iberian Coast. OSPAR Commission, London. 134 + xiii p.

Parra, S. and E. López-Jamar. 1997. Cambios en el ciclo temporal de algunas especies infaunales como consecuencia del vertido del petrolero "Aegean Sea". Publicaciones Especiales Instituto Español de Oceanografía, 23: 71-82.

Pingree, R.D 1979. Baroclinic eddies bordering the Celtic Sea in the late summer. Journal of the Marine Biological Association of the United Kingdom, 59: 689- 698.

Pingree, R.D. 1993. Flow of surface waters to the west of the British Isles and in the Bay of Biscay. Deep-Sea Research, 40(1/2): 369-388.

Pingree R.D. 1994. Winter warming in the Southern Bay of Biscay and Lagrangian eddy kinematics from a deep-drogued Argos Buoy. Journal of the Marine Biological Association of the United Kingdom, 74: 107-128.

Pingree, R.D. and B. Le Cann. 1990. Structure, strength and seasonality of the slope currents in the Bay of Biscay region. Journal of the Marine Biological Association of the United Kingdom, 70: 857-885.

Pingree, R.D. and B. Le Cann. 1992a. Three anticyclonic Slope Water Oceanic eDDIES (SWODDIES) in the southern Bay of Biscay in 1990. Deep-Sea Research, 39(7/8): 1147-1175.

Pingree, R.D. and B. Le Cann. 1992b. Anticyclonic eddy X91 in the southern Bay of Biscay, May 1991 to February 1992. Journal of Geophysical Research, 97(C9): 14353-14367.

Porteiro C., J .M. Cabanas, L. Valdés, P. Carrera, C. Franco, and A. Lavín. 1996. Hydrodynamic features and dynamics of blue whiting, mackerel and horse mackerel in the Bay of Biscay, 1994-1996. A multidisciplinary study on Sefos. ICES CM. 1996/S: 13.

Quéro, J.C. and o. Cendrero. 1996. Incidence de la peche sur la biodiversité ichthyologique marine: le bassin d'Arcachon et le plateau continental sud Gascogne. Cybium, 20(4): 323-356.

Quéro, J.C., J. Dardignac, and J.J. Vayne. 1989. Les poissons du golfe de Gascogne. IFREMER/Secrétariat de la Faune et de la Flore, 229 p.

Quéro, J.C., M.H. Du Buit, and J.J. Vayne. 1997. Les captures de poissons a affinités tropicales le long des cotes atlantiques européennes. Annales Societe des Sciences Naturelles de la Charente-Maritime, 8(6): 651-673.

Quéro, J.C., M.H. Du Buit, and J.J. Vayne. 1998. Les observations de poissons tropicaux et le réchauffement des eaux dans l'Atlantique européen, Oceanologica Acta, 21(2): 345-351.

Ríos, A., F.F. Pérez, and F. Fraga. 1992. Water masses in the upper and middle North Atlantic Ocean east of the Azores. Deep-Sea Research, 39: 6 5-658.

Robles, R., C. Porteiro, and J .M. Cabanas. 1992. The stock of Atlanto-Iberian sardine, possible causes of variability ICES Marine Science Symposium, 195: 418-423.

Roemmich, D. and J. McGowan, J. 1995. Climatic warming d the decline of zooplankton in the California current. Science, 267: 1324-1326.

Roy, C. 1993. The optimal environmental window hypothesis: A non linear environmental process affecting recruitment success. ICES M 1993/L: 76.

Sánchez, F. and J. Gil. 2000. Hydrographic mesoscale structures and Poleward Current as a determinant of hake (Merluccius merluccius) recruitment in southern Bay of Biscay. ICES Journal of Marine Science. 57:152-170.

Sánchez, F., F. de la Gándara, and R. Gancedo. 1995. Atlas de los peces demersales de Galicia y el Cantábrico. Otoño 1991-1993. Publ. Esp. Inst. Esp. de Oceanogr. 20:99 p.

Sánchez, F., I. Olaso,.and.R. Goñi..1997. Changes in bottom trawl survey catch rates in dogfish (Scyhorhinus canicula) and thornback ray (Raja clavata) in the Cantabrian Sea between 1983-1997. Working document for the 1997 WGECO meeting.

Santiago, J. 1997. The North Atlantic Oscillation and recruitmen of temperate tunas. SCRS/97/40.

Saunders, P.M. 1982. Circulation in the Eastern North Atlantic. Journal of Marine Research, 40 (Supl.): 641- 657.

Sherman, K. and A.M. Duda. 1999. An ecosystem approach to global assessment and management of coastal waters. Marine Ecology Progress Series, 190:271-287.

Sournia, A., J.M. Brylinski, S. Dallot, P. Le Corre, M. Leveau, L. Prieur, and C. Froget. 1990. Fronts hydrologiques au large des c6tes françaises: Les sites-ateliers du programme frontal. Oceanologica Acta, 13(4): 413-438.

Southward, A.J. and G.T. Boalch. 1994. The effect of changing climate on marine life: Past events and future predictions. Exeter Maritime Studies,! 9: 101-143.

Southward, A.J., S.H. Hawkins, and M.T. Burrows. 1995. Seventy years' observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. Journal of Thermal Biology, 20(1/2): 127-155.

Stocker, T.F. 1994. The variable ocean. Nature, 367: 221-222

Stouffer, R.J., S. Manabe, and K. Ya Vinnikov. 1994. Model assessment of the role of natural variability in recent global warming. Nature, 367: 63 -636.

Taylor, A.H. 1996. North-South shifts of the Gulf Stream: Ocean-Atmosphere interactions in the North Atlantic. International Journal of Climatology, 16: 559-583.

Taylor, A.H. and J.A. Stephens. 1997. The north Atlantic Oscillation and the latitude of the Gulf Stream. Tellus, 48 A.

Turrell, W.R., R.R. Dickson, S. Narayanan, and A. Lavín. 1997. Ocean climate conditions in the ICES North Atlantic region 1996/1997. ICE S CM 1997/EE: 9.

Uriarte, A., P. Alvarez, S. Iversen, D. Kennedy, M.M. Martins, J. .Massó, J. Molloy, E. Mullins, S. Myklevoll, and B. Villamor. 1998. Spatial Pattern of Migration and Recruitment of Northeast Atlantic Mackerel. Rep9rt to the European Commission of Project 96-035, March 1998.

Valdés, L. and M. Moral. 1998. Time series analysis of copepod diversity and species richness in the southern Bay of Biscay (Santander, Spain) d their relationships with environmental conditions. ICES Journal of Marine Scie ce, 55: 783-792.

Valencia, V. 1993. Estudio de la variación temporal de la hidrología y el plancton en la zona nerítica frente a San Sebastián entre 1988-1990. Informe Técnico Gobierno Vasco, 52, 105 p.

Varela, M., S. Barquero, B. Casas, M.T. Alvarez-Ossorio, and A. Bode. 1995. Are variations in salinity of north Atlantic central waters affecting plankton biomass and production in NW Spain? First IGOFS International Scientific Symposium. Villefranche-sur-Mer, France. Mayo, 8-12, 1995.

Varela, M., A. Bode, and N. González. 1998. Intrusiones de agua Nordatlántica de origen subtropical y fitoplancton durante la primavera en el Golfo de Vizcaya. 6° coloquio Internacional de Oceanografía del Golfo de Vizcaya. San Sebastián, Spain.

Villate, F., M. Moral, and V. Valencia. 1997. Mesozooplankton community indicates climate changes in a shelf area of the inner Bay of Biscay throughout 1988 to 1990. Journal of Plankton Research, 19(11): 1617-1636.

Whitehead, *P.I.P.*, M.L. Bouchot, *I.C.* Hureau, *I.* Nielsen, and E. Tortonese. 1984. Fishes of the North-eastern Atlantic and the Mediterranean. Vols I, II, III. UNESCO, Paris. 1473 p.