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9 The French Atlantic Coasts

P. Dion and S. Le Bozec

9.1 Introduction

Summer mass blooms of macroalgae have been occurring increasingly for two decades along the French Atlantic coastline (Fig. 9.1). The coasts of Brittany are the most affected, considering the nearly 100 000 m^3 of green seaweeds collected yearly from the beaches. One member of the genus *Ulva* is particularly involved in these mass blooms, although some ectocarpales, for example *Pilayella littoralis*, recently appeared in some localities.

The enclosed Bay of Arcachon is the second most affected area with about 6000 m^3 of green algae removed yearly. Eutrophication also occurs, at least as a natural phenomenon, in the 30 000 ha of salt marshes of the French Atlantic coast.

The present knowledge of the eutrophication mechanisms producing the green tides on the Brittany coasts is presented here. Possible fighting means (curative as well as preventive measures) are also reviewed.

9.2 Green Tides of the Brittany Coasts

The term "green tides" in Brittany generally refers to concentrations of unattached forms of *Ulva* sp., occurring in summer in the nearshore waters (Fig. 9.2), and leading locally to massive beaching (Fig. 9.3).

Green tides are not in themselves a hazard to human health, and a negative impact of decomposing deposits on the ecosystem has not yet

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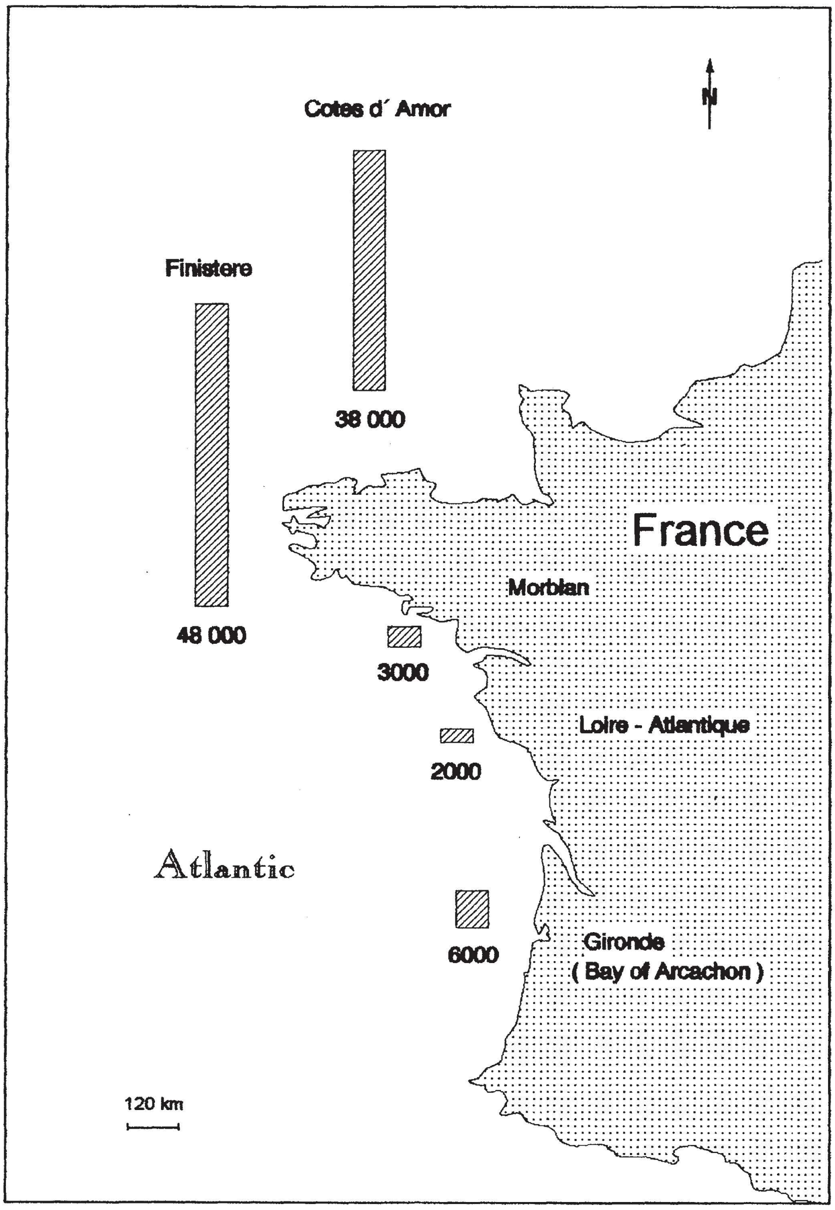

Fig. 9.1. Beach cast (stranded *Ulva* sp. in t wet weight) removed from beaches along the coast of France in 1991

been demonstrated. However, by making the beaches unattractive (visual and odoriferous pollution) during the summer period, they force coastal townships and municipalities to undertake a costly removal scheme in recreational or living areas. Moreover, immeasurable costs probably originate with a decrease in a general degradation of the reputation of the Brittany coastline. It should also be added that massive development of seaweeds can be a physical hindrance for small coastal navigation or mariculture, for example, shellfish cultivation. The hydrodynamic situation along the exposed Brittany coasts with strong swells and tidal water movements prevents degradation of the algal masses in the water

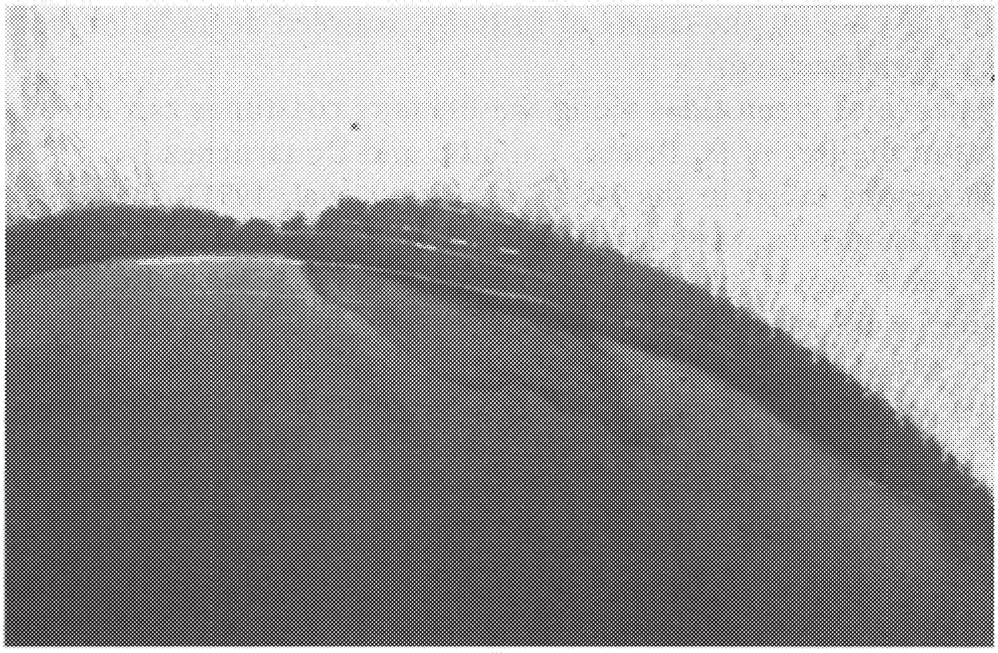

Fig. 9.2. Unattached forms of green tide *Ulva* sp. forming a distinct floating belt at low tide along the beach, Bay of Lannion, Brittany. The belt can be 20 to 200 m wide. Note the breaking swell concentrating the seaweed in the very shallow nearshore waters (0 to 1 m depth). Aerial infrared photograph, IFREMER

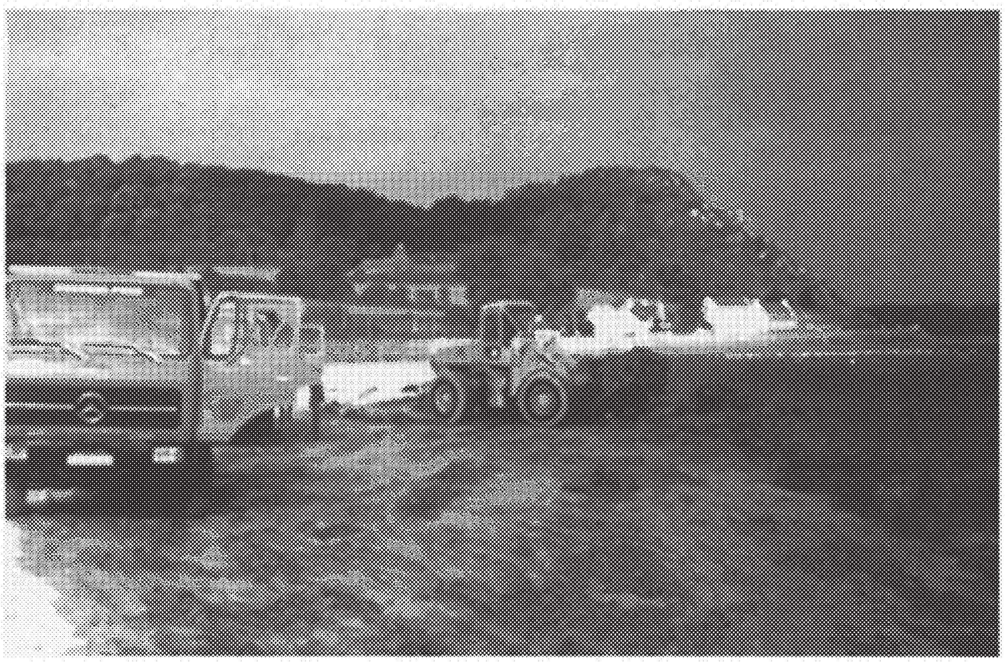

Fig. 9.3. Stranded biomass of green tide forming *Ulva* sp

column, such degradation could cause a dystrophic crisis (i.e. oxygen consumption and depletion) at the end of the growth period, as has been observed in shallow closed lagoons (e.g. Mediterranean pools, Venice lagoon: see Chap. 15, this vol). In green tide-infested areas of the "open type", as is the case for the coasts of Brittany, seaweed degradation only takes place after beaching.

The existence of green tides along the Brittany coastlines can already be detected in the Bay of St. Brieuc, Lannion and Douarnenez from IGN aerial photographs taken in the 1950s (cf. Piriou et al. 1991). In the late 1970s, the phenomenon of green tides became evident, and reached an intolerable point only in its recent evolution, during the 1980s. The extent of these green tides now seems to be stabilized in these main sites, but it has been observed that each year an increasing number of coastal communities and townships are reported to be affected (50% increase between 1983 and 1991; Fig. 9.4).

During the summer of 1991, about 25% of these localities were affected by green tides and some of them, particularly seaside resorts, had to undertake cleanup operations. Thus, 98 000 m^3 were collected from the coasts of the four Breton departments. It should be pointed out that not all of the stranded seaweeds were collected and that there is no simple relationship between beaching levels and total production.

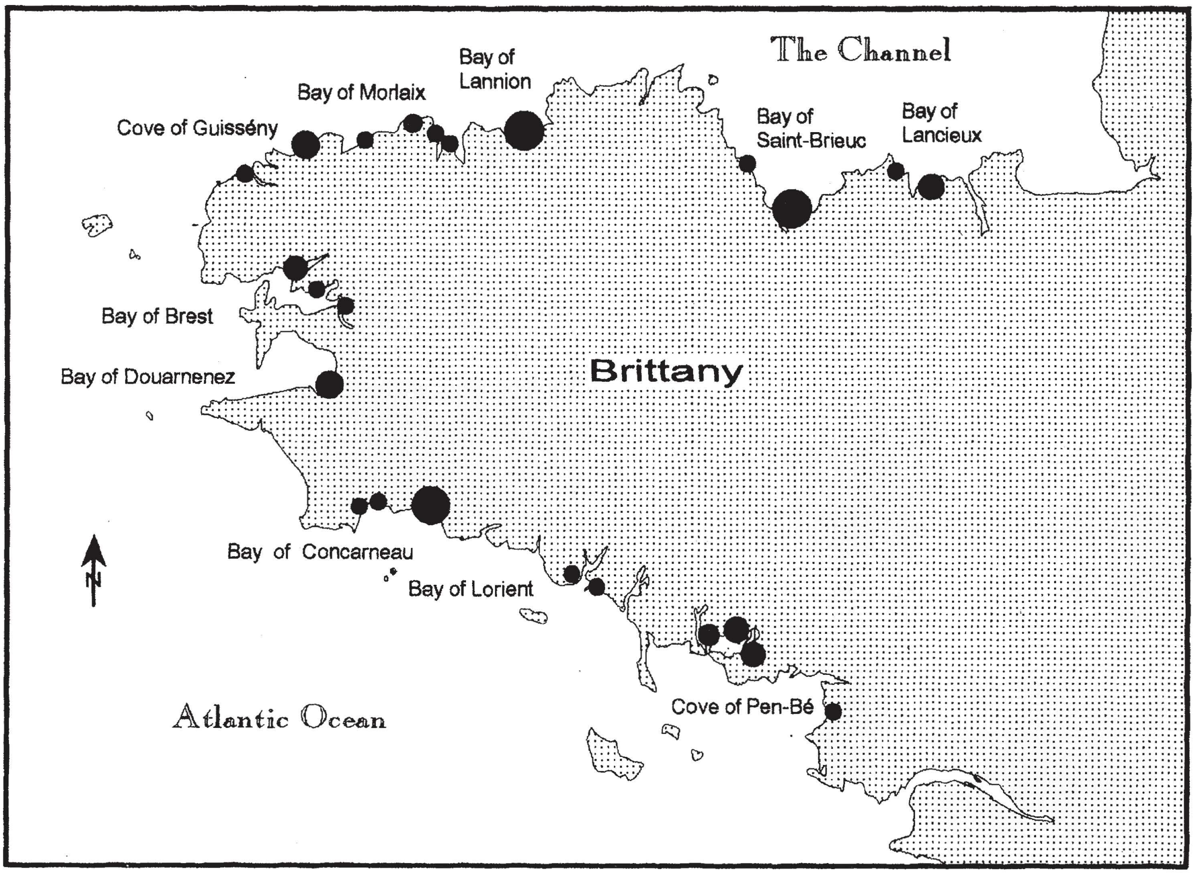

Fig. 9.4. Spatial distribution of *Ulva* sp. mass blooms on the Brittany coast

9.2.1 Production Mechanism of Green Tides

The term green tide generally refers to drifting *Ulva* concentrated along sandy portions of the shoreline. The species involved occur also attached to rocky and gravel substrates of the lower intertidal zone. These attached populations are the primary source of green tides on the coasts of Brittany, but there is now evidence that they are not of preponderant importance in the annual formation of the phenomenon. In fact, attached populations of these species are not particularly abundant around affected areas. In addition, no whole individuals or basal parts with their holdfast can be found in the floating green tide material, which would indicate a recent removal from substrate and direct transport. It is likely that material transfer from attached to free-living populations is small. The bulk of the green tide production occurs in the floating phase, through vegetative reproduction. In spring, the source of the green tide is most probably a remnant of *Ulva* from the preceding year.

Mass development of green seaweeds in other coastal areas of Europe and all over the world is generally attributed to an increase in the nutrient concentrations in coastal waters. In most cases, green tides can be directly linked to that of waters collected by drainage basins. The most responsible nutrients are nitrogen and phosphorus compounds.

On the Brittany coast, enclosed areas, such as the inner parts of bays, where water exchange with the sea is slow, are particularly sensitive to green tide outbreaks (Menesguen and Salomon 1988; Piriou et al. 1991, 1993). Despite the high tidal amplitude of 6–9 m, residual drift of the waterbody between tides is small, as shown in the Bay of St. Brieuc (Menesguen and Salomon 1988). Drifting seaweed and nutrients are therefore trapped together in these areas. Breaking swell, which usually occurs in large intertidal areas with a low slope, probably takes part in concentrating the seaweeds in shallow nearshore coastal waters. Keeping the seaweeds in suspension in this enriched, mixed, easily warmed up and well lighted environment favours rapid growth and vegetative multiplication through fragmentation.

Out of the eight species of *Ulva* that it is possible to identify around the coast of Brittany (Hoeksema and Van den Hoek 1983), only one is involved in large-scale green tide processes. The systematic position of this species is not clear, and a new taxonomic nomenclature will probably have to be put forward for it. Its predisposition to react to eutrophicating conditions at the end of bays seems to be based on particular biological and physical characteristics (Dion 1990).

Ulva species in general, and the *Ulva* form producing mass blooms on Brittany coasts in particular, have a high photosynthetic potential, allowing efficient use of the summer light conditions for growth (Table 9.1).

Table 9.1. Comparison of photosynthetic potentials at saturating light (2000 $\mu E\ cm^{-1}\ s^{-1}$) and 15°C between green tide *Ulva* sp. and other seaweed life forms

Species	Photosynthetic potential ($mg\ O_2\ g\ dry\ wt^{-1}\ h^{-1}$)
Ulva sp. (green tides)[a]	60–80
Ulva rigida[a]	30–40
Enteromorpha compressa[b]	25–35
Fucus vesiculosus[b]	7–13
Petrocelis cruenta[c]	1–2

[a]Data from CEVA.
[b]Data from Levavasseur (1986).
[c]Data from Dion (1988).

Compared with other seaweeds (Table 9.2), the green tide *Ulva* species shows high nutrient uptake performances. The ratio V_{max}/km, which is often used to characterize the affinity of seaweeds for nutrients (e.g. Wallentinus 1984), is very high for the green tide *Ulva* sp., demonstrating its opportunistic behaviour in the use of nutrients.

The wide temperature optimum for growth, ranging from 17–23°C as determined in laboratory experiments (CEVA, unpubl. data), shows that this species is well adapted to the temperature conditions of shallow waters in flat sandy bays, which easily warm up. Water temperatures close to the beach may be as high as 28°C during the flood period. (The open sea temperature never exceeds 18°C).

Table 9.2. Kinetic parameters of the green tide *Ulva* sp. under batch and laboratory conditions (data from CEVA, unpubl. and for other seaweeds data from Wallentinus 1984)

A. Phosphorus uptake

Species	V_{max} ($\mu mol\ PO_4^{-3}\ g\ dry\ wt^{-1}\ h^{-1}$)	V_{max}/km
Ulva sp.(green tides)	8–35	4–10
Enteromorpha spp.	2–8	2–6
Fucus vesiculosus	0.6–1	0.2–0.4

B. Nitrate uptake

Species	V_{max} ($\mu mol\ NO_3^-\ g\ dry\ wt^{-1}\ h^{-1}$)	V_{max}/km
Ulva sp.(green tides)	60–230	12–37
Enteromorpha spp.	27–130	8–16
Fucus virsoides	5–20	0.5–1.3

Survival and, consequently, mass production of the green tide *Ulva*, would not be possible if it could not maintain itself suspended in the mixed water column and multiply easily by fragmentation. The thinness (30–40 μm) and fragility of the thallus are probably conditional to these capabilities. Generally, the seaweeds involved in eutrophication seem, in the same way, able to colonize the water column physically.

As far as other species are concerned with regard to eutrophication on Brittany coasts, it should be mentioned that agglomerations of unattached mixed *Porphyra* species have been found irregularly in small quantities since the first reports of the green tide phenomenon. They have very rarely led to quantitatively significant beachings.

More important is the brown alga *Pilayella littoralis* (Ectocarpales), which has been recently noted to produce mass blooms in some localities of North Brittany. Such blooms occur irregularly from one year to another, sometimes in alternation with *Ulva* sp. Mass development of *Pilayella littoralis* has also been observed along the coasts of other countries, e.g. USA (Massachussetts), and the Baltic Sea (Breuer and Schramm 1988; Pregnall and Miller 1988). In the same way, the filamentous red alga *Falkenbergia rufalonosa* (sporophyte of *Asparagospsis armata*) has been recently shown to produce mixed mass blooms with the green tides of the Bay of Douarnenez (South Brittany), indicating trends in diversification or succession for species involved in local coastal eutrophication (CEVA, unpubl. data).

9.2.2 Fighting Means and Associated Research Programs

What methods could be used for fighting green tides on the coasts of Brittany? In this context, the relationships between attached and free-floating populations must be considered. The attached populations of the *Ulva* species are scattered and not easily distinguishable from each other. In practice, it is difficult, even un-feasible to operate selectively on these populations. Furthermore, this action on the whole would probably be useless, since sessile populations are not a major cause of the annual formation of green tides, as was pointed out earlier.

As to the control of floating populations, curative and preventive means may be distinguished.

Curative means include collecting the seaweeds and removal, or the direct use of growth inhibitors or toxic compounds. Collecting the beached biomass is commonly used to clean up recreational areas, although this method has its limitations and is often expensive (3 million FF in 1992 for the coasts of Brittany CEVA, unpublished data). Another possibility would be to collect enough seaweeds from those already in the water at the start of the proliferation period to prevent an outbreak of green tides. However, this does not appear to be very feasible from a technical and economic point or view. In addition, storage of collected seaweed masses is an environmental problem in itself. Treatments such as methanization or composting are now technically perfected (Briand 1989), but it is difficult to reach an industrial breakthrough.

At the present state of scientific progress, direct application of any chemical or microbiological method, which would lead to growth inhibition or destruction of the green tide-forming plants, is not ecologically acceptable.

After curative means, preventive means have to be considered. Of the primary environmental factors controlling growth and mass development of the seaweeds, light and temperature, of course, cannot be altered. Undoubtedly, the only realistic preventive means to reduce green tides is to lower nutrient levels in sensitive coastal areas. Three different aproaches are possible, at least theoretically.

1. *Physical Means.* Collecting or rerouting nutrient-loaded waste water has already been used on different scales to prevent coastal zone pollution. This solution would be theoretically possible in some locations of Brittany (e.g. Bay of Lannion), where river discharge is comparatively small and could be canalized or piped out of the sensitive zone. In the Bay of St. Brieuc, rerouting of tidal channels would probably help decrease green tides to a certain extent (Piriou et al. 1991).
   Generally speaking, physical solutions have the disadvantage that they can only be applied in particular cases. In addition, they require major investments, and they do not decrease, but only transfer the pollution problem (even if diluted) from one area to another, with unpredictable long-term effects.
2. *Preventive Means of the Biological Type.* These could, for example, include the cultivation of economically valuable seaweeds that would compete with *Ulva* for nutrients, or the settlement of macrophyte swamps or wetlands, the purifying effect of which is well known (cf. Reddy and Smith 1987). Their disadvantage is that they would require large land or sea areas, which are rarely available along the Brittany coast.

   The possibility of using wetlands in Brittany was first considered (in 1990) for the Fremur river (Departement of Côtes d'Armor), which has at least a potential of 80 ha for the wetland settlement. The estimated cost for such a project, however, was discouraging for the local authorities. A smaller and more experimental project was started recently in the Bay of Douarnenez (Piriou 1993). The introduction of seaweed cultures as nutrient competitors for the green tides (see Chap.4, this vol.) was considered in some favourable situations but was not followed up because there was no demand by the local seaweed industry for such quantities of seaweeds which would be necessary to substitute or outcompete the green algae.

3. *Preventive Means of the "Chemical" Type.* These concern decreasing the input of nutrients already upstream in the drainage basin by efficient effluent treatment and a preventive policy.

In this context, research programs have been undertaken at CEVA and IFREMER to study the physiological ecology of *Ulva* nutritient requirements and to develop ecological models.

Seasonal variations of N and P content in *Ulva* tissues clearly indicated that external nitrogen N was the major limiting nutrient for green tide growth (Dion 1988; Piriou and Menesguen 1992; Fig. 9.5).

Ecophysiological laboratory investigations also contributed to a numerical model for the ecological production of *Ulva* (Menesguen and

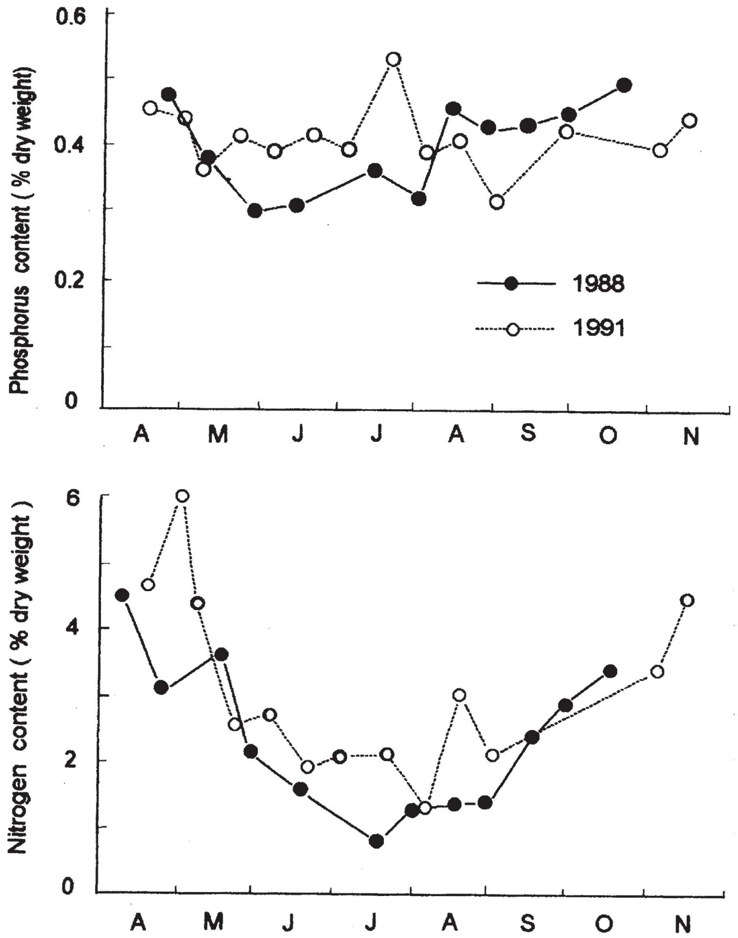

Fig. 9.5. Seasonal variations in internal N and P contents in green tide *Ulva* sp. during mass bloom in the Bay of St. Brieuc, 1988 and 1991 (CEVA, unpubl. data)

Salomon 1988; Menesguen 1990; Piriou and Menesguen 1992). With the help of this model it was possible to quantify the limiting role of N for growth, and to predict relationships between N and P flows and green tide development in the Bay of St. Brieuc.

Reducing the nitrogen input at the river basin level is undoubtedly the most suitable way (if not the only one available) to prevent green tides in the long term. This solution, however, introduces serious short-term economical problems, in particular when intensive agriculture is the main source of nutrients, as is the case in Brittany. The effects of phosphate removal in wastewater treatment plants have been monitored as an alternative solution in the Bay of St. Brieuc over a period of 5 years. Despite a 50% reduction in the total phosphorus load and a considerable reduction (60%) in tissue phosphorus levels in *Ulva* sp., mass development of green algae continued to occur (CEVA, unpubl.).

9.3 Other Cases of Eutrophication Along the French Coast

9.3.1 The Bay of Arcachon

The Bay of Arcachon in southwestern France is an example of a relatively closed marine bay, where mass proliferation of green macroalgae occurs. The area of the bay (150 km^2) is divided at low tide into three NE–SW oriented main channels, which are connected with the Atlantic Ocean through a strait (Fig. 9.6). The total low tide area of the main and secondary channels is about one-third of the total Bay area (cf. Auby et al. 1994).

The Bay of Arcachon is well known for its attractive landscape, favouring an important seasonal touristic economy. The bay is urbanized, and crowded in summer. The other basis of the local economy is mariculture, in particular oyster cultivation, producing 15 000 to 20 000 t of oysters per year.

The general topographic conditions in the bay and the tidal regime allow oyster production in the intertidal zone and the presence of 7000 ha of seagrass meadows (*Zostera noltii*) whies colonize mobile sand and the mud substratum.

Macroalgal mass blooms have been occurring in the Bay of Arcachon for many years, but they have become conspicuous only recently, because of increased production of green algae in the water body, and the

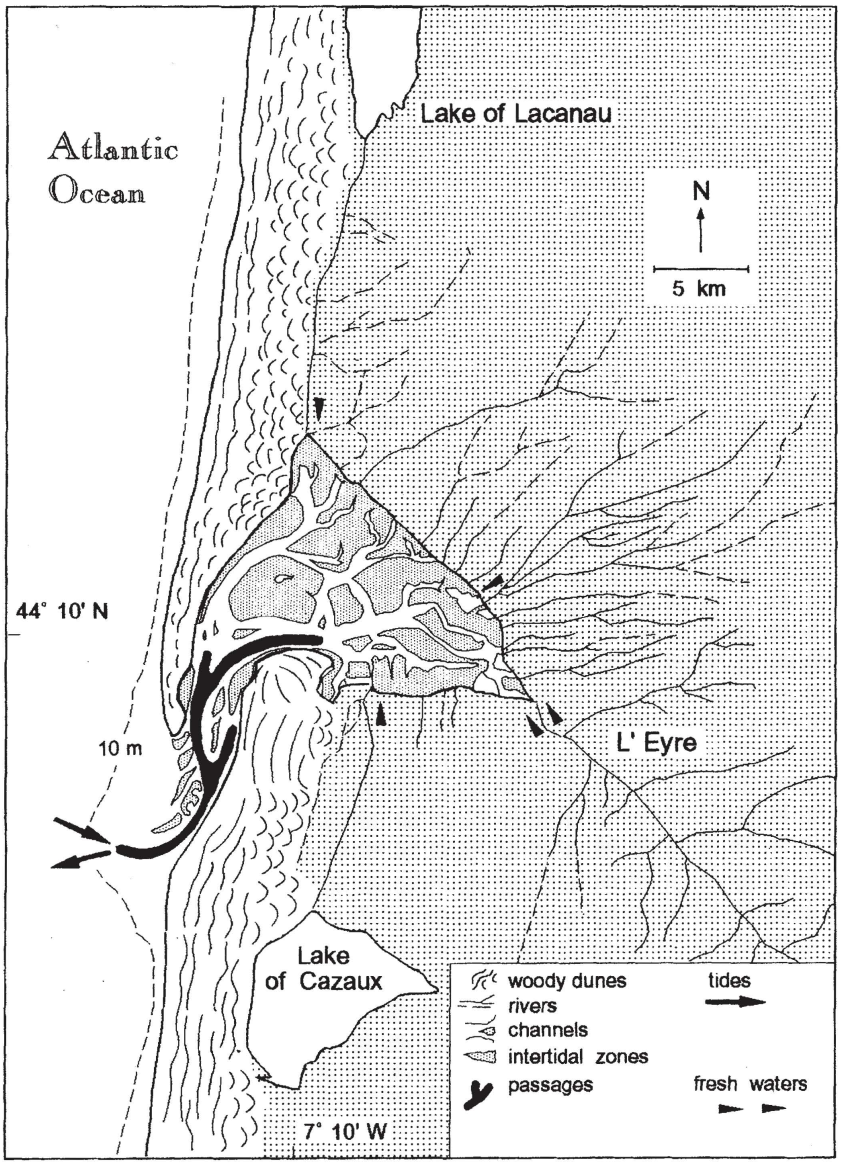

Fig. 9.6. The Bay of Arcachon

strandings of these seaweeds in the large muddy intertidal zone and on tourist beaches. During spring tides and windy periods, large amounts of green algae mixed with drifting *Zostera* are frequently deposited on the muddy and sandy strands, where they decompose rapidly. Because it is a nuisance for fishery and tourism, the decomposing material has to be removed mechanically.

The collected beach cast increased from about 4000 m^3 in 1990 to 30 000 m^3 in 1992, the latter containing about 6 000 m^3 of *Monostroma*, indicating a rapid increase in the green tide phenomenon in this region.

According Auby et al. (1994), mass production of *Enteromorpha* sp. first appeared in the Bay of Arcachon in 1982. This species had been noted earlier at this site but in acceptable amounts. Seasonally, the development of *Enteromorpha* sp. is rapid in June in the intertidal zone, where populations are attached to the substratum, partly in the *Zostera* beds. During this period, the size of the plants increases, until they are torn off from their substrata, then invading the water body where they continue to grow free-floating. This phenomenon usually ends in October. Such proliferation can lead to various detrimental effects including anoxia and fish mortality.

Another green alga has become the dominant species in the bay since 1989; it was identified as *Monostroma obscurum* (Auby *et al.* 1994). The period of maximum biomass development is between January and April, i.e. before the bloom or *Enteromorpha* sp. The vegetative propagation of the unattached thalli is probably the principal way of producing large biomasses, in the subtidal channels and in the shallow water of the intertidal zone. During other periods, significant quantities of algae can be maintained in the water, and they do not completely disappear in autumn and winter. For a few years, the filamentous red alga *Centroceras clavatum* was also observed to produce blooms sporadically in the Bay of Arcachon. Concerning *Monostroma* at least, nitrogen is considered the limiting nutrient.

9.3.2 Eutrophication and Salt Marshes

Salt marshes of the French Atlantic coast cover about 30000 ha from the Gulf of Morbihan (southern Brittany) to the Bay of Arcachon (Aquitaine) and extend mainly in the Régions Pays de Loire and Poitou-Charentes (Fig. 9.7). They consist of complex hydraulic systems of channels and ponds, which used to be exploited by the salt industry in the past and are partly utilized for shellfish aquaculture today.

The natural productivity of these systems is very high and macroalgal blooms occur frequently in the ponds. *Ulva* spp. and *Enteromorpha* spp. are the main species responsible for the mass blooms, but other green seaweeds (*Cladophora* spp., *Ulothrix* sp., *Chaetomorpha* spp.), as well as brown algae (*Colpomenia peregrina,* some members of *Ectocarpaceae*) or red seaweeds (*Gracilaria verrucosa*) also invade the ponds depending on the localities, the seasons and the ponds' management procedures. Such macroalgal blooms can cause dystrophic conditions in the ponds, but also may compete for nutrients with phytoplankton, the food base for shellfish aquaculture. The removal of the seaweeds uses up a considerable proportion of the working time and efforts of the aquaculturists.

The development of eutrophication and pollution by trace elements has recently received attention, particularly in areas where intensive agriculture has spread to the buffer wet zone besides the salt marshes.

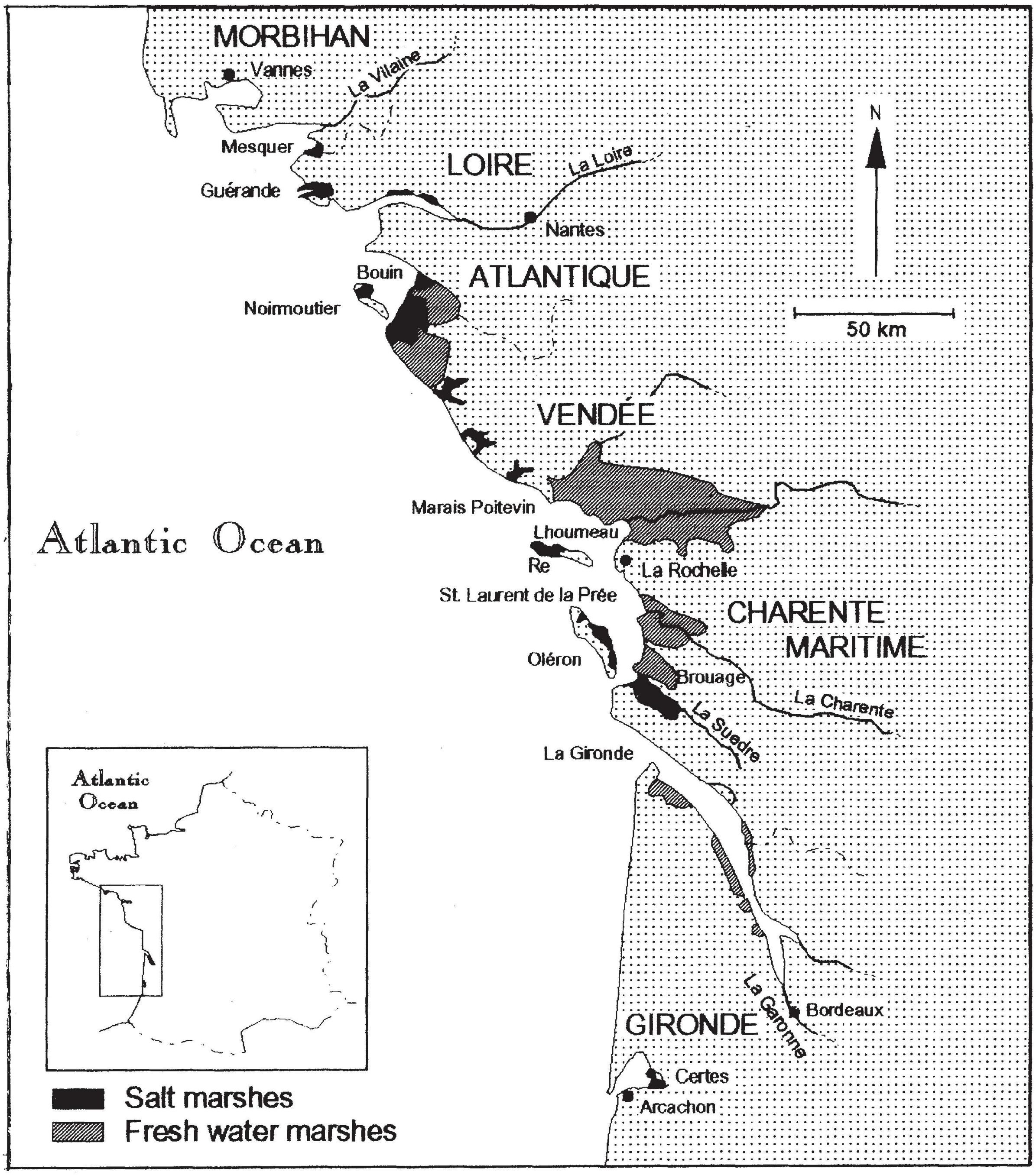

Fig. 9.7. Localization of the French Atlantic salt marshes. (From Clement 1991)

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