



Green Tides on the Brittany Coasts

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For over a decade the European Commission has funded the programs aimed at examining the problems of algae production, their utilization and green tides. COST and BRIDGE have led to publication of two volumes surveying the situation, principally on the Atlantic and Mediterranean coasts of Europe. Two presenters of this paper are members of the team and co-authors of the books. The volumes center on Europe, and the presenters have been principally concerned with the eutrophication and the bioconversion of seaweeds. Research has led to a series of proposals to alleviate the accumulation of stranded algae, mostly *Ulva*, and their disposal or, at least, their partial utilization in agriculture, industry and even energy production. The paper reviews and summarizes their conclusions, several not yet published, putting an accent on the methanization, and draws a parallel with a prevailing situation in south-eastern Florida. Related topics include: anaerobic digestion of *Ulva*, bioconversion of algae, composting of *Ulva*, management of eutrophication, and the “seaweeds” programs of the European Commission.

Key words: *algae, green tide, utilization*

1. Introduction

Tides have received rather varied polychromatic labels. It reminds one somewhat of “coal” as French people see it: black, white, green, gold. Similarly, there are black, red, brown and green tides. The latter, once considered a plus, are a rather unpleasant development carrying dire economic consequences, for tourism in particular. Brittany, a leading tourist region of France, has known three “colors” of tides. The red ones are due to *thanatocoenoses* of *dinoflagellates* (a reminder: the designation of red tide has also been occasionally given to proliferation of red algae), whereas some of the most publicized black tides from oil spills have affected tourism and ostreiculture for years. Brown tides have been reported only in the north-eastern United States where *Phaeocystis* engenders *Prymnesiophite* blooms resembling a foamy gelatinous mass (Cosper, 1989). And then there are the green tides, a major and costly nuisance due to excessive growth and stranding of seaweeds, striking again—among others—Brittany (Fig. 1).

Gathering of seaweeds is an ancestral activity in Brittany where they were, and to some extent still are, used as a fertilizer for spring produce, livestock feed and even fuel (Chapman and Chapman, 1980). This rosy picture of the past is even enhanced when one considers several private firms and various laboratories, now established in the former province, that grow, study and transform algae into green, red, brown.

Even if some of these organizations cultivate seaweed, it is the surplus of algae that poses a problem (Charlier, 1991). This problem is anyway present all over the world. For instance, in Europe, not only France is coping with the problem of green tides. At the end of the '80s the lagoon of Venice was afflicted by an important growth of *Ulva*. For the moment the plague is regressing. In the shallow Baltic Sea, the worst problem concerns the migration of algae towards the sea-bottom that is destroying the benthos.



Fig.1. Green tide in Lannion Bay (Brittany, France) prior harvesting - photo: Xavier Briand (Briand, 1989)

2. Green Tides on the Atlantic Coast of France

Studying eutrophication, Briand noted that in 1985, 1987 and 1989 green algae particularly affected by proliferation were mostly *Ulva*, *Enteromorpha* and *Cladophora*, and among the red algae *Gracilaria* and *Porphyra*, with a very great dominance of *Ulva* along the French Atlantic coasts (Brault et al., 1985; Briand and Morand, 1987; Briand, 1989).

The areas such as the Bays of Lannion and St Brieuc (Brittany) were notably affected as early as in the late '70s (Kopp, 1977). In 1986 in a single season some 25,000 m³ w.w. of

Ulva spp. accumulated in the Lannion Bay. In 1996, however, the affected areas had already spread to the regions of Aquitaine, the site of the Landes' lakes, particularly in the Arcachon Basin (Auby et al., 1994), Normandy and, above all, Brittany along all its coasts (Fig. 2). In the case of Lannion an additional loss of 500 metric tons per year of sand results, while no less than 2000 truck round trips are necessary to remove the algae loads. In general, along the Brittany coasts, *Ulva* decompose either in situ or in large drifts.

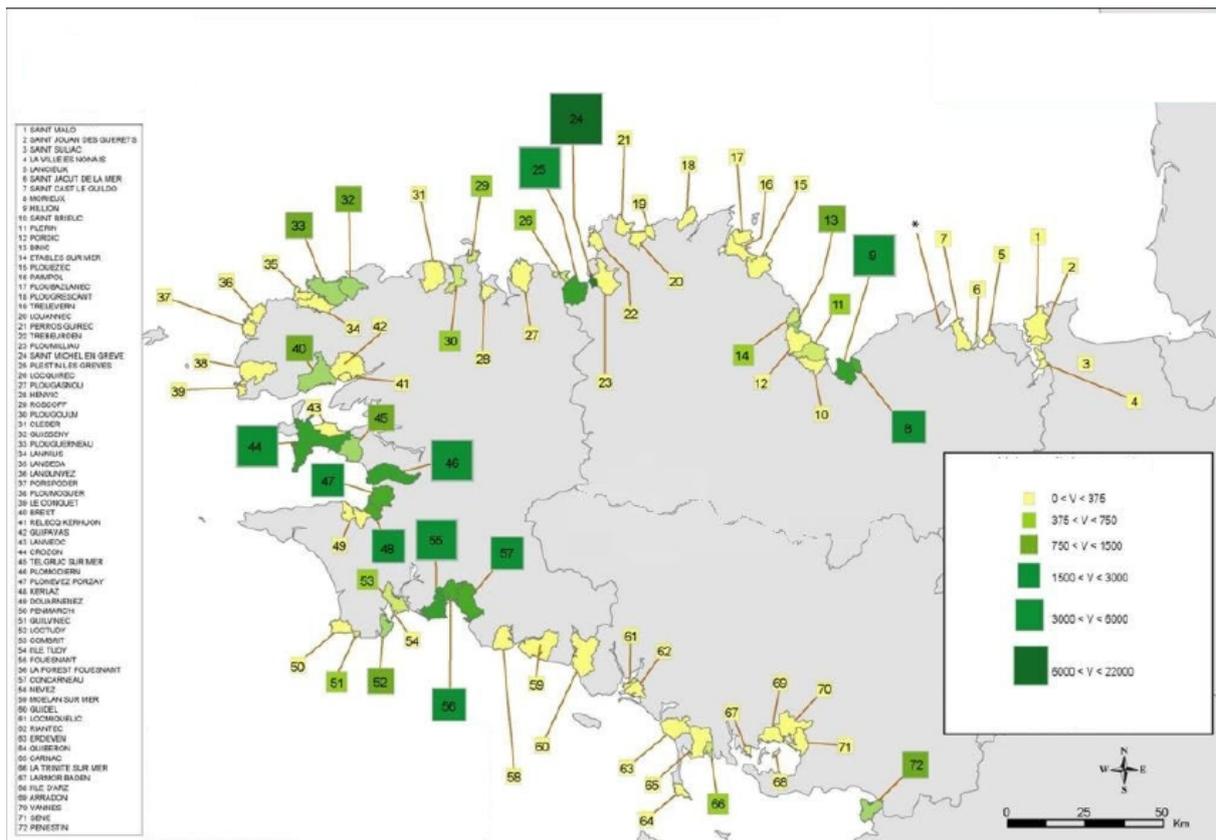


Fig. 2. Map of Brittany showing the coastal municipalities collecting "green tides" algae. The ranges of collected volumes (V) for 2004 are on the right of the map. The total volume for the 72 municipalities is 69,225 m³ while the expenses involved reach 610,000 €. The collection carried out in the bay of La Fresnaye (*) is not included because it is subjected to experimentation. The list of municipalities is on the left. (Based on the map drawn up by CEVA in the framework of the Prolittoral programme CEVA, 2004)

Cleaning the beaches encompasses the use of sifting machines, raking machines, scraping machines, *goëmoniers* (the engine is based on the principle of agricultural harrows. The word is also used to indicate a person that collects algae to be used for instance as fertilizer. Similarly the raking machine is based also on agricultural machines; it is used where accumulations are not too thick) and even bulldozers where, such as on the Bay of Lannion, the masses are so large - they occasionally reach one meter heights. Briand (1991) remarks that the collection rate varies from 300 to 700 m³ per hour; however the process is not adjusted to avoid picking up sand as well. He mentions also a craft which cleans up coastal waters, but such an equipment is not currently in use in France.

Table 1 shows the problems inhabitants and tourists had to cope with over a 4-year span, in addition to foul odors. Hillion is a small town near St Brieuc, previously graced with beaches that were among the preferred of the bay; today, depending on

the wind direction, the bay's green tides occur (Fig. 3). A less intensive harvest spreads in that region as there is more time to make decision for that site than in the Bay of Lannion, because of a more regular deposition of algae, the problems are continuous all summer long, thus precluding the use of the beaches (Fig. 4).

The collection bill per metric ton, footed by the taxpayer, varies from € 7.60 to 122 depending on the area covered and equipment put to work.

In Brittany, the culprits for eutrophication and green tides are said to be predominantly agriculture, leaching of fertilized soil by rainwater, nutrients of atmospheric origin contained in rainwater, nitrogen fixation by blue-green algae or *cyanobacteria*, nutrients from artificial ponds and sea-farms such as food surplus and fish excreta.



Fig.3. Green tide on a beach of Hillion, in the Bay of St Brieuc (Brittany, France) - photo : Sotiris Orfanidis

Table 1. Quantity of *Ulva* harvested at hellion (1989-1992).

Year	Harvesting parametres	May	June	July	August	September	Total
1989	Quantity of <i>Ulva</i> harvested (m ³)	3780	2257	2812	925	1137	10,911
	Number of days of harvesting	11	7	11	2	3	34
	Average daily quantity (m ³)	344	322	255	463	379	320
	Maximum daily quantity (m ³)	500	500	333	463	444	500
1990	Quantity of <i>Ulva</i> harvested (m ³)	2187	2214	3421	2039	149	10,010
	Number of days of harvesting	8	10	16	10	3	47
	Average daily quantity (m ³)	273	221	214	204	50	213
	Maximum daily quantity (m ³)	365	243	365	243	81	365
1991	Quantity of <i>Ulva</i> harvested (m ³)	403	3885	5511	3148	653	13,600
	Number of days of harvesting	2	12	16	10	4	44
	Average daily quantity (m ³)	201	324	344	315	163	309
	Maximum daily quantity (m ³)	245	542	630	472	297	630
199	Quantity of <i>Ulva</i> harvested (m ³)	155	5737	3605	3603	1460	14,560
	Number of days of harvesting	1	19	10	15	7	52
	Average daily quantity (m ³)	155	300	360	240	208	279
	Maximum daily quantity (m ³)	155	550	550	525	380	55



Fig. 4 *Ulva* collected on a beach of Hillion, in the Bay of St Brieuc (Brittany, France). Photo: Jacques Maze

3. Algal Problem in South-eastern Florida

Damages to the environment, ecosystems and related developments were reported by Finkl and Charlier (2005). Consequences due to algal proliferation parallel the observations on the other side of the Atlantic.

The development of algae blooms (principally *Gracilaria tikvahiae*, *Laurencia poitei* and *Codium isthmocladum*) along the south-eastern coast of Florida was the subject of studies for more than a decade and a half (La Pointe et al., G.S., 1990). Adverse environmental impact was periodically and seasonally evident. As a consequence of decaying corals and macroalgae presence, the near shore water quality deteriorates. Tourism is affected by the declining “quality” of the beaches. As a result the beach-generated income markedly decreases.

Eutrophication and general degradation characterize the third largest coral reef system in the world. Urbanization is also a causal agent: the association between algal blooms and septic tanks upland, generators of N-laden effluents, has been drawn. Discharge of polluted freshwater has favored *Codium* blooms. Agricultural run-offs are leading culprits.

4. Biomass use

The efforts are taken to use the garnered algae: they are used as fertilizer, mixed with waste to be composted, or sometimes dehydrated and mixed in poultry feed. Many approaches to commercialization of the algal biomass have been suggested, e.g. bioconversion; in Brittany this would require very long return time investments with particular conditions (Morand et al., 1991). In St Brieuc, shore pollution was transformed to land pollution, where dumping was performed. Now, algae are used as raw fertilizer in some sites close to the sea or, for a small

part, they are brought to an area of household waste treatment.

Tests were run to check on possible seaweed use in water purification, and nutrient recycling (Schramm, 1991). That involved specific types of wastewater with excessive proportions of nitrate present; it had to be purified to be made fit for human consumption. Oddly enough, the algae could be used as an agent to remove excess nutrients from the polluted ecosystem. In Brittany, tests were rather performed in the areas close to the sea with *macrophytes* but not seaweeds growing in fresh water (Piriou et al., 1999).

Could seaweed play a role in power production? They were used as a fuel in Brittany. Studies conducted over the years determined ten years ago that a therm would cost between 10 and 18 euro-cents, more than double that of a therm produced from gas-or-oil at 5 euro-cents (7 euro-cents from propane and 3 from wood). That cost is a far memory today and the price is much more likely 10 to 15 euro-cents.

5. Composting – a Method of *Ulva* Stabilization?

The Centre d'Aide par le Travail (CAT) de 4 Vaulx-Jardin mixed algae with ligneous material and animal faeces to make high quality compost. In order to deal with the great quantity of algae, it studied the means for decreasing their mass and volume before transporting them to a composting plant to enter in the composition of composts. Work performed at Hillion (St Brieuc Bay) became a successful attempt at composting them with a minimum of ligneouscellulosic substrate (Morand et al., 1992).

Composting the algae with the lowest quantity of *ligneous-cellulosic* substrates results in the stabilization of the seaweed, and thus their use can be delayed. This system of processing the seaweed decreases the cost of treatment by composting (Mazé et al., 1993). In separating the pre-treatment step, the

area on concrete bases or under cover can be reduced by a factor of three.

The product can then be used either as a substrate for later composting or as an organic enhancing and fertilizing agent. Transport to fields further from the coast becomes possible while currently fertilizer use remains restricted to the areas within a relatively short distance. Unfortunately, in Brittany, trials for building a plant did not succeed until now, neither at Hillion, for political reasons, nor at St Cast, near St Malo and Dinard, because of the rejection by the local population, the chosen site being too close to their houses, where a timid approach was made to mix algae with such ligneous materials as green wastes and hedge clippings, in order to obtain a stabilized product following a method derived from the 4 Vaulx-Jardin system.

6. Methanization and Pressing

In several countries "green tides" algae are harvested to play a role in pollution abatement scenarios. In Brittany where *Ulva* is the main component of the tide, research efforts centered on the possible use of the algae as a methanization substrate.

In batch, biogas production starts rapidly but requires 40 to 60 days of fermentation under mesophilic conditions. Thus, with about a 60-day retention time, 44 to 75% of the substrate energy is recuperated. These results show clearly the aptitude for mesophilic fermentation of *Ulva*. However, shorter retention times lead to lower recuperation. The volumetric yield of *Ulva* completely stirred methanization is always low, if *Ulva* is not only ground, but also pretreated by degradation or centrifugation (Carpentier, 1986; Orlandini and Favretto, 1988). In fact, methanization is hampered by high viscosity of algae, and a compromise is required between productivity and biological yield.

The process combining two steps, hydrolysis and juice methanization, is a technique which offers a reasonable compromise between methane output, productivity of the system and treatment cost (Morand and Briand, 1999). However, it comes up against two problems. (i) Productions are strongly dependent on climatic conditions. (ii) The recuperation rate of COD or of methane potential is significantly too low. Improvement may be brought to both by use of pressing. Only in this way will it be possible to consider the "green tides" hydrolysis process to be used on a large scale.

In the fermentation process a solid/liquid separation would occur between the acidogenic and methanogenic phases, warranting extraction of the organic pollution, whereas the results of pollution abatement and energy production would depend on its effectiveness. Technologically, the devices permitting this solid/liquid separation, excluding centrifugation, generally combine filtration with mechanical compression. The extraction obtained depends then on resistance of the substrate to filtration and on the operating parameters (Baskerville et al., 1971). The

equipment for extraction therefore is to be adapted to the two fermentations constraints: quality of the substrate stemming from the acidogenic fermentation, and suitability of the filtrate as regards the parameters governing the methanic fermentation¹. Of the various presses tested, the screw press proved best to recover a large quantity of sufficiently loaded pressing juice after only a short hydrolysis time (Table 2).

This process saves time and reduces the digestion volume (Morand et al., 2006). Using the hydrolysis juice collected by first draining then pressing as a methanization substrate, the resulting cake can be used as an enriching or fertilizing organic agent in agriculture (Fig. 5). The quality of the *Ulva* juice also makes it suitable as substrate for industrial processes, alternative or co-substrate of methanization in pre-existing reactors, all the more, if their production be spread over several locations. Thus the subsequent investment can be dispensed with.

Table 2. Balance sheet of recovery of CODt, NH₄⁺ and energy during hydrolysis and screw press pressing steps. Extracted from Morand et al. (2006).

Characteristics	Acidogenic fermentation	Pressing	Sum for the two steps filter
Juice (L/50 kgVS)	168	204	372
COD (kg/50 kgVS)	1.9	11.6	13.5
NH ₄ ⁺ (kg/50 kgVS)	0.05	0.18	0.23
CH ₄ equivalent (L kg ⁻¹ VS)	13.4	77.4	90.8

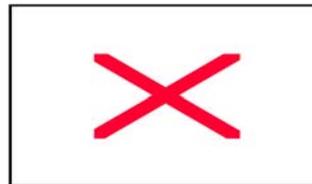


Fig. 5. Synoptic scheme of *Ulva* sp. treatment by separation of acidogenic and methanogenic phases. 1: Acidogenic reactor. 2: Predigested muds. 3: Screw press. 4: Pressed muds. 5: Storing tank of hydrolysis juices. 6: Methanogenic reactor. 7: Biogas boiler. 8: Gasometer. The two steps may be separated in different places

7. Conclusion: an Environmental "Must"

The environmental impact of algae proliferation can be assessed in terms of organic load, nitrogen, phosphorus and hydrogen sulphide pollution (Morand Briand, 1999). Were the 11,000 t of *Ulva* stranded in

¹ Reid and Jackson (1956) obtained a pressing cake of *Ascophyllum nodosum* (Linnaeus) Le Jolis, fit for agricultural use, by drying the algae with a press band filter. Pretreatments have also been tested for the Venice Lagoon algae (Missoni and Mazzagardi, 1985; Orlandini and Favretto, 1988).

the Lannion Bay to decompose on the coast, the ecosystem would take in some 20 t N and 2 t P, for an initial composition of *Ulva* on average 20 mg N g⁻¹ dry matter and 0.2 mg P g⁻¹ dry matter (Briand and Morand, 1997). Such quantities can be compared to urban pollution. Renewed three times in one year, they correspond to the annual wastes generated by a city of more than 12,000 inhabitants such as Lannion. Surmising that these quantities would be available *in toto* for *Ulva* growth, the recycling would cover 60% of the needs necessary to maintain the production level. The reuse of nutrients by opportunistic algae is a permanent feature: it has been shown in several cases, for instance in the Peel Inlet Bay (Australia) (Gabrielson et al., 1983), in the Lunkebugten Bay, a shallow bay of the archipelago of southern Fyn (Denmark) (Thybo-Christesen et al., 1993), or again in the Venice Lagoon (Italy) by Sfriso et al. (1993).

Ulva harvest and its treatment are an absolute necessity as there is an added production of 50,000 m³ H₂S (Wilkinson, 1963; Charlier and Morand, 2005). Interest for green seaweeds' bioconversion by anaerobic fermentation links pollution abatement and energy production.

However, methanization of the entire seaweed requires a digester of a significant size, handicapping an acceptable economic return (Briand and Morand, 1997); the hydrolysis of the entire seaweed, directly followed by methanogenesis - two-step methanization - with natural recovery of the liquefaction juice, likewise stumbles on the economic obstacle, the long time needed for hydrolysis brings about a high cost (Morand and Briand, 1999). Adding the pressing of the hydrolyzed *Ulva* mud has to be envisaged. The recent report concerning this technique allows to sum up the technical and economic balance of a possible method to handle the *Ulva* green tides scourge (Morand et al., 2006).

The needed investment to treat 25,000 m³ of harvested algae hovers around € 0.6 million. The development of this type of treatment needs government agencies to cover the extra cost of pollution abatement as return times are economically unacceptable. Algae have a potential role in pollution abatement efforts and could possibly be used for energy production. They have been so in the past and there have been proposals to use them for electricity generation. This has been discussed by Flowers and the others in the USA (Charlier and Justus, 1993). Salinity often limits utilization of algal-based products in agriculture. Use of waste in algae ponds is another potential solution enabling nutrients recycling through biomass production. But, for the moment, the alternative of the treatment by stabilizing composting is, following the local conjuncture, notably the possibility of setting up a plant without trouble for and from inhabitants, the most interesting solution, economically, for a treatment on a relatively small scale.

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Žalieji potvyniai Bretanės pakrantėse

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Dešimtmetį Europos Komisija finansavo dumblių gamybos, panaudojimo ir žaliųjų potvynių tyrimo programas. COST ir BRIDGE išleido dvi knygas, kuriose ištirta Atlanto ir Viduržemio jūros pakrančių situacija. Du šio straipsnio autoriai yra tos komandos nariai ir minėtų knygų bendraautoriai. Knygose daugiausia buvo kalbama apie Europą, ir daugiausia dėmesio buvo kreipiama į jūros dumblių eutrofikaciją ir biokitimus. Mokslininkai pateikė keletą pasiūlymų, kaip sumažinti pakrantės dumblių kaupimąsi, daugiausia *Ulva* rūšies dumblių, kaip jų atsikratyti, ar netgi kaip būtų galima juos iš dalies panaudoti žemdirbystėje, pramonėje ar energijos gamybai. Straipsnyje apžvelgiamos ir apibendrinamos mokslininkų išvados, kelios jų dar nebuvo publikuotos, pagrindinis dėmesys skiriamas pelkėjimo (metanizacijos) procesui bei vaizduojami panašumai su pietrytinėje Floridos dalyje vyraujančia situacija. Susijusios temos apima: anaerobinį *Ulva* skaidymą, dumblių biokitimus, *Ulva* kompostavimą, eutrofikacijos valdymą, ir Europos Komisijos jūros dumblių programas.