Monitoring of green tides on the Brittany coasts (France)

Dorian Gravier

Supervisors: Angela Wulff & Anders Torstensson

Department of Biological and Environmental Science, University of Gothenburg, Sweden.

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A B S T R A C T

The eutrophication is one well known consequence of human society developing. This leads to several negative impacts, notably on coasts with green tides, characterize by important and abnormal macroalgal proliferation. In France, since the seventies the region Brittany is the most hit area, with the genus Ulva. Proliferations are explained by species plasticity and competitiveness, no limitation in nutrient and certain topographic conditions. Side-effects affect at the same time the environment and the human society. To understand and to heed this phenomenon, a monitoring is done since 1978, but is really effective since 2002. Number sites affected, surfaces concerned and volumes collected by communities are principal followed parameters. To have an idea of the real evolution of green tides, parameters have to be analyzed together, due to limits in measurements done for each. It could be for instance the definition of sites, the evolution in sampling methods or community participation in surveys. Efforts have been done since 1990 to reduce nitrogen inputs, permitting the reduction of 14% of nitrate levels in surface water (difference between 1998 and 2007). This level is still too high to reduce significantly algae proliferation. Knowledge are now more than sufficient to improve making-decisions which will enhance water quality and reduce green tides.

1. Introduction

1.1. Green tides in the world

Since few decades the impact on human society lead to changes in marine and freshwater ecosystems [1]. Certain changes are indirect, induced by eutrophication and the hypertrophication, resulting in different consequences in Europe (*cf* Fig. 1 [2]). One impressive example is green tides phenomenon which can be characterize by huge macroalgal proliferation, usually green or red algae [3, 4]. Those proliferations are now common all over the world [1, 3, 5, 6] and in 1996, they were occurring in 25 countries in the world [4]. The first report was done in Belfast Lough in 1911 [4, 7] and they became widespread between 1960-1970 . In 1996, they were occurring in 25 countries in the world [4]. In France, the region Brittany is the most impacted and was already affected at the beginning of the sixties, with problems occurring since the seventies [8, 9, 10].

1.2. Characteristics of proliferating species in Brittany

Green tides in Brittany can be mostly due to green algae proliferations, from the genus called *Ulva* (*cf* Fig. 2 [11]) [6, 12, 13, 14, 15]. This one is really efficient to proliferate and create such blooms, due to its physiologic plasticity and its important competitiveness : a high nutrient uptake performance and an easily multiplication by fragmentation [3, 16, 17]. 9 species were documented in this region : *lactuca* [12], *rigida, olivascens, gigantea, curvata, rotundata, scandinavica, pseudocurvata and armoricana* [18]. *U.armorica* and *U.rotundata* are respectively the most proliferated species in the North and the in South of Brittany [19].

1.3. Causes

Green tides are usually induced by an eutrophication of the water, which can be defined as “an acceleration of chemical inputs that favour photosynthesis and influence algal populations” [20]. In Brittany, those blooms appear since nitrogen (N) was no more the limiting factor. Phosphorus (P) is not considered as a limiting factor in this area (*cf* Fig. 3 [17, From 21 in]) [1, 9, 16, 17, 21]. In this region the eutrophication is predominantly induced by agriculture [1, 6], but rainwater containing nutrient of atmospheric origin, nitrogen fixation by blue-green algae or cyano-bacteria, nutrients from artificial ponds and seafarms (food surplus and fish excreta) must not be disregard [6].

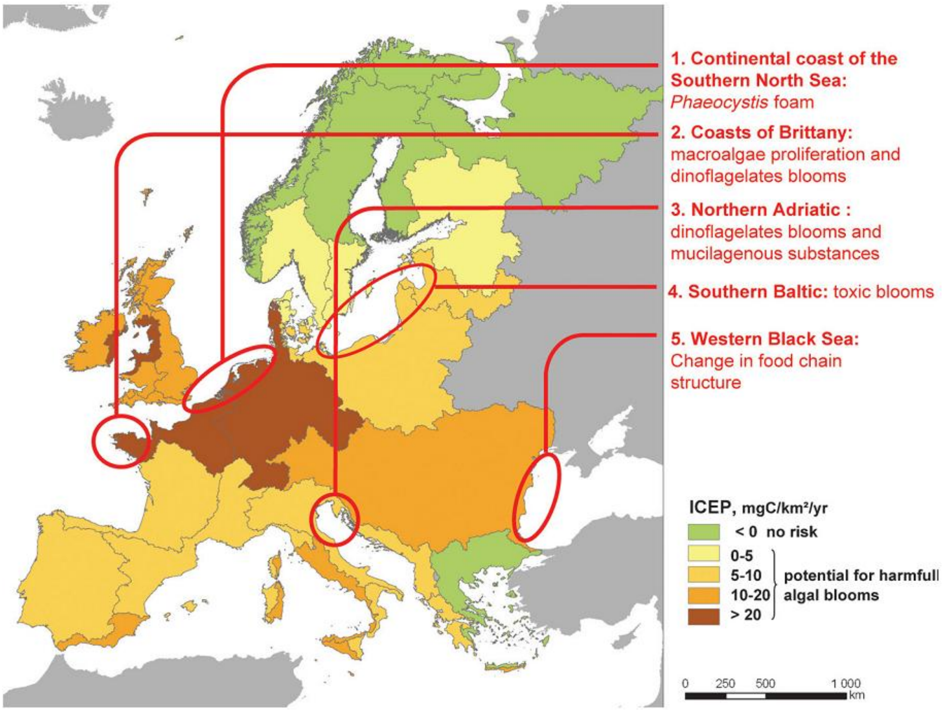

Fig. 1 : "Calculated Indicator of Coastal Eutrophication Potential (ICEP) by European coastal region, based on the data from Table 13.5 . Identification of the major coastal areas where eutrophication problems are recorded" [2].

Fig. 2 : Aspect of the majority of *Ulva sp.* Photography [11].

A freshwater supply with a sufficient nutrient flow directly leading to the zonal production [8, 17] is not the only parameter needed to permit the proliferation of *Ulva sp.* Those different characteristics are also important:

- A broad and flat foreshore [8, 9, 17]
- An important lighting intensity and duration, especially in spring [9, 16, 22]
- A sea water temperature at least superior to 13-14°C and quick warm up in spring [6, 16, 22]
- An important water transparency [7, 9]
- A turbulence strong enough to keep the algae suspended [9]
- A containment of water masses and nutrients [8, 9, 17, 23]

1.4. Impacts

Green tides in general have different negatives impacts affecting at the same time the environment and the human society. The environment can be touched physically by a restricting water movement and velocity, increasing sedimentation rates and modifying the oxygen transport [1].

Fauna communities can be modified, sometimes advantageously for instance for crabs recruitment [24] or for densities of some benthic species [25] but more often disadvantageously, for the benthos [1, 17, 26, 27], or sedentary species, especially bivalves and tube-dwellers [25].

The real impact of green tides on flora is not really studied, since macroalgal proliferations are induced by eutrophication which also affects all other flora species. In all case it has been shown that the quantitative increase in benthic algae result in a general impoverishment of flora richness and diversity [1, 28, 29, 30]

Algal stranding result in an increasing concentration of certain compounds in the air or in the soil (hydrogen sulphide, N and P ...) [4, 6]. This can lead to certain environmental pollution as in part responsible in acid rains, and soil pollution (on beaches and groundwater when algae are put in discharges) [6, 9]. Important concentration in hydrogen sulphide can provoke animals and humans death. Since 2008, dogs, horses, a truck driver (not really proved) and boars (*cf* Fig. 4 [31]) died by being present a too long time near an algal stranding [17, 19, 31].

In Brittany, negative economic consequences have followed first tides. The tourism has decreased since the seventies due to the strong discomfort and inability to perform most of the usual entertainment [6, 9, 17, 19]. They also affect fishing and shellfish activities, by clogging nets, trawls and recovering mussel beds [9]. To top it all, the removal of the material and the disposing of it lead to a financial and economic stress on communities [3, 6, 17, 19]. In 2010, the collected cost supporting by Brittany's communities was evaluated around 1 150 000€ [32].

2. Discussion

2.1. Monitoring of green tides

In 2000, the European Union Water Framework Directive (WFD) was adopted, leading on a real and official monitoring of macroalgae blooms. Since 1978, green tides are followed by the Algae Study and Valorisation Center (CEVA) but is really effective since 2002 with the Prolittoral program (until 2006). Today the monitoring is always done in partnership with the Ifremer which is responsible to follow algae blooms in Loire and Brittany

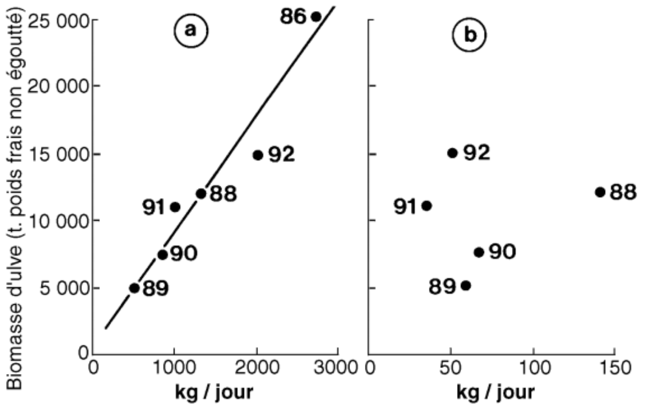

Fig. 3 : "Relation between maximal annual biomass of *Ulva sp.* in Saint-Brieuc bay and nutrient flux on the site in June". (a): N flux; (b): P flux. X in kg per day and Y in tonnes [From 21 in , 17].

Fig. 4: Dead boar found at the mouth of Gouessant (river in Côte d'Armor – Brittany) [31].

regions. Really few documents are relating monitoring methods used by the CEVA and usually they are not explained in details (example with [32, 33]). The monitoring can be divide in 3 different parts: (i) number of hit sites, (ii) surface concerned, and (iii) volumes collected. For each one, some explanations and a rapid analyse are exposed below.

2.2. Number of hit sites

Counting sites is done by plane at low tide twice per year (sometimes three times). The definition of a stranding site depend on the abnormal amount of green algae detectable by plane and a field control to be sure that it is well *Ulva sp.*, if they are free and if they represent more than 1/3 of the stranding. The number of sites must be used with caution since some represent a little *Ulva* surface (between 10 and 100m² for instance) with a part of them concernin mudflats. One bay (example of Douarnenez bay) can be decomposed in (11) different sites. The covered surface by *Ulva sp.* is without doubt more precise to have an idea of the evolution of green tides year after year, especially if we consider that the definition of "sites" has certainly evolved since the first monitoring supply. The number of sites has certainly increased rapidly since the seventies but it is difficult to be sure that data reflect a precise trend. Some data of the CEVA expose this number of sites (beaches or mudflats) between 1997 and 2010 [32]. The problem is that data are not comparable due to some differences in sampling dates, as in sampling efforts (*cf* Fig. 5 [34]). In this figure, comparison is only possible intra-colours. For beaches the trend is not really pronounced since 2000 and we can see that there are important fluctuations between years. The little increase after 2008 is certainly due to a better monitoring. The relative stabilisation of this number could be partly explained and the geographical distribution is not extremely different since 1988 [9], and as we can see on Fig. 6 the volume collected roughly stayed in a mean of 45 000-50 000m3. Number of touched mudlflats is roughly increasing and could be partly explained. Firstly the increasing after 2008 is not comparable with previous years due to changes in the sampling method which is more systematic ([32] - see below in 2.3 p3) resulting in higher sites number . Secondly, sites are more known by the CEVA and more effort in the monitoring was allocated [33]. Thirdly, the annual evolution of covered area is slower than in bays and beaches, differences in physical, chemical characteristics and in species interaction (competition for instance) could have slow down the "invasion" of *Ulva sp.*

2.3. Surface concerned

The proliferation importance is evaluated by a surface approach. Concerning bays and beaches, the surface is estimated with aerial photography, and one major problem is to have good weather conditions. Sometimes the view angle is quite important and photography must be georectified which could result in some errors in calculated surfaces. In all case, estimations seem to be well done and the evolution year after year since 2002 cer-

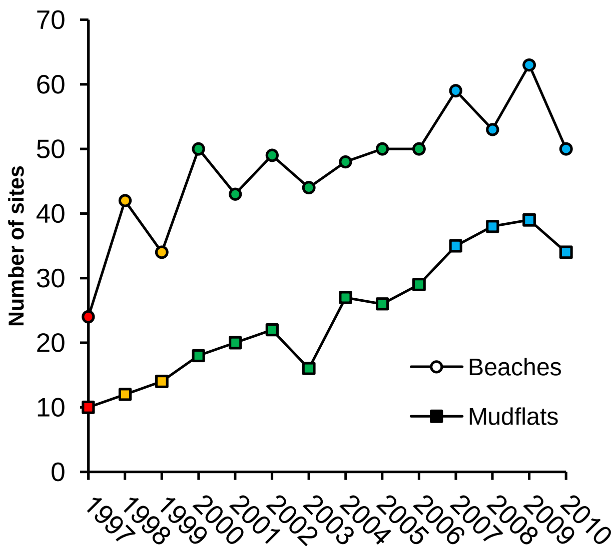

Fig. 5 : Number of touched sites by stranding of *Ulva sp.* in Brittany between 1997 and 2010. Color : RED - 1997: incomplete inventory; ORANGE - in 1998 and 1999: 1 plane monitoring per year; GREEN - 2000-2006: 2 plane monitoring per year (in July and August); BLUE - 2007-2010: 2 plane monitoring per year (July and September). Before these dates, a plane monitoring sampling was done in 1988, 1991 and in 1994 [9], but no data have been found. Data synthesized from the CEVA [34].

tainly give a good idea of the reality.

Concerning the appreciation of the area covered by *Ulva sp.* in mudflats, it is more difficult to trust data in the same way. Firstly, tools used by the CEVA were developed only for beaches in bays and for "monogenus" green tides as *Ulva sp*. In fact, mudflats are usually composed of filamentous green algae and *Ulva sp.* look exactly the same from the sky. Secondly, field accesses are quite difficult and time consuming leading on the impossibility to verify it as on beaches and in bays. Thirdly, methods have evolved. Before 2008, cover surfaces of *Ulva sp.* were estimated when they seemed to be at their maximum and only if the layer of this genus was continuous. The term "maximum" is not really explained, and no details are exposed on how they made the difference by using aerial photography. Since 2008, filamentous and blade green algae were merged to appreciate their annual surface, always by using the date when they are the most represented or by using the date "with the most exploitable photography" [32]. Difficult to understand the real meaning of these latter words.

In all case authors considered all of this and decided to divide the analysis between green tides on beaches and in mudflats, which is the better choice. A good solution to compare the real evolution between locations is to use the surface covered between water bodies. In another hand it could be interesting to compare the ratio (R) between water bodies surfaces with the one covered by green tides in each. If we compare the rank of water bodies on the surface covered by green tides and with the one of this R ratio (Wilcoxon III test - paired sample), there is no significant differences (p-values : 0.737 for mudflats and 0.341 for beaches). This ratio (R) does not really reflect which water body is more touch than another.

Those methods take in account only the algal intertidal stock (surface zone and stranded ashore), but another stock can be located (in the most affected sites) beyond the surface zone (subtidal stock), at 7m depth minimum, and with the same weight range as the intertidal stock. This one is significantly more abundant in late winter or early spring than the intertidal stock. Moreover both stocks seem to be related and one could supply the other [5, 35]. The dynamic between them can explain some proliferations variation year after year but the subtidal stock is not taken in account by the CEVA methods. In all case it is not clearly written even if one document [36] expose that winter stock are followed.

2.4. Volumes collected

Since 1978, the CEVA heed *Ulva sp.* collecting by communities. These data are not necessarily a good indicator to follow green tides evolution, but is still a good one to have an idea of the negative impacts that they provoke to the population [33]. Collecting depend on several things: money available, if a subvention is allocated for it, cost, beach access, touristic pressure, weather and topography conditions, lunar cycle [36] and communities awareness (that is better each year, especially since 2002, date of the beginning of the Prolittoral program). By synthesizing different data (*cf* Fig. 6 [32] [17]), it is possible to see that the volume collected in Brittany seems to follow the number of communities responding to the survey, this is in part logic.

As explained before, the number of sites (bays and beaches) does not really follow the trend of the volume collected. The survey is certainly well done by the CEVA and more communities reply every year with more details. One thing could be improved : be sure that communities without collecting volumes the years before, reply even if no volume were amassed. It is always possible that some communities confuse *Phaeophyceae* macroalgae (common since a long time) with *Ulva*, rising on no collecting data. A part of sand and sea water is amassed during collecting, emerging in an overvaluation of the real algal weight. This part stays certainly relatively stable each year at the scale of the region, but locally highly depends on the equipment and the thickness of the deposits. In better cases, algae (dry weight) only represent 50% of the weight amassed [36].

2.5. Water quality

Ulva sp. is used since a long time in Brittany [37] and they can be used as human [1, 38] and animal alimentation [1], as soil compost, as biogas [1, 15], as biofuel [6], to extract fine chemicals as ulvans [1, 39] or to purify waste water [6]. But green tides ensue on punctual and massive algae volumes, restrict an industrial exploitation, except maybe as compost which is already done at a low cost [7].

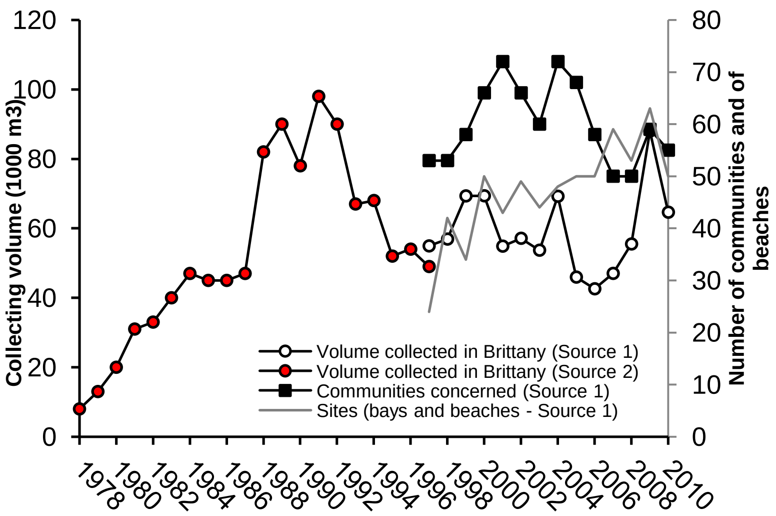

Fig. 6 : Evolution of green algal volumes collected in Brittany, in comparison with the number of communities responding to the survey and the number of bays and beaches touched by green tides (Data synthesized from the CEVA found in [32]: source 1 , and in [17]: source 2).

Since the weather conditions and natural habitats could not be controlled, the only mean to reduce green tides to the source is to decrease N input [2, 7]. Several references show that agriculture is the main source of nitrogen input in Brittany. For example, over 30 years in Brittany, rivers nitrates concentration have fourfold increased (*cf* Fig. 7 [40]) and animal production increased by 3 at the same time [40]. Now "the farmed livestock (mainly pigs, cattle and poultry) generate by their effluents a pollution equivalent to that of approximately 50 million inhabitants, that is to say 15 times more than the population of the region" [6]. Fig. 8 ([41]) shows that there is a significant and important N-surplus for agricultural soils in Brittany, and this has a negative consequence on N input to aquatic ecosystems as shown in Fig. 9 ([41]). This latter also divulges that for France the diffusion from agricultural soils is higher that the European average: about 65% against 57%. The case of Brittany is certainly bigger than this percentage.

Fig. 10 ([42]) indicates that the agriculture also release important amount of NH_3 in the air, and this must not be shelved even if a little part is absorbed by green algae in general [7].

Since the vote in 1991 of the Nitrates Directive and the establishment of different voluntaries measures, farmers have been able to do some efforts. This has resulted between 1998 and 2007, of a decrease in nitrate concentration by 5mg/l in Brittany surface waters. The nitrate level is still at 30mg/l in 2007 (*cf* Fig. 11 [43]), and the guide value is 25mg/l for human health [19, 43]. Scientists know that it will not be enough to reduce green tides since the level is higher than 10 mg/l, corresponding to the level 50 years ago [7, 19, 44, 45].

The time scale to see improvement after the reduction of N-input will be long, certainly more than 10 years [2]. Even if a fairly short reaction time (between 2 and 10 years) has been observed after the nineties with a decrease in agricultural pressure [40]. The work and efforts must come from everywhere, especially politics than must give the financial possibility to farmers to move to an ecologically productive agriculture [19].

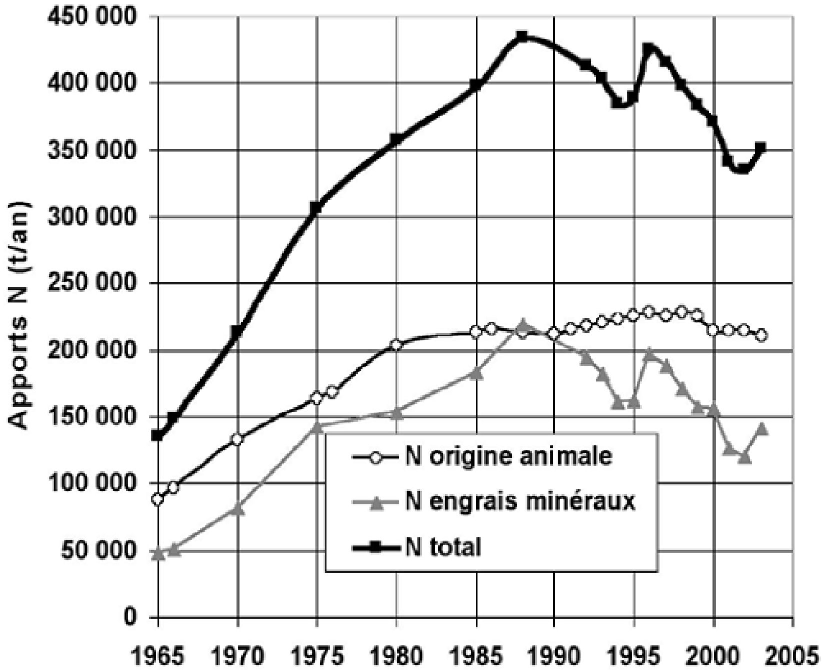

Fig. 7: N input by organic manure and mineral fertilizers in Brittany. Y : N-input in tones per year, N origine animale : N coming from animals, N engrais minéraux : mineral fertilizers. [40].

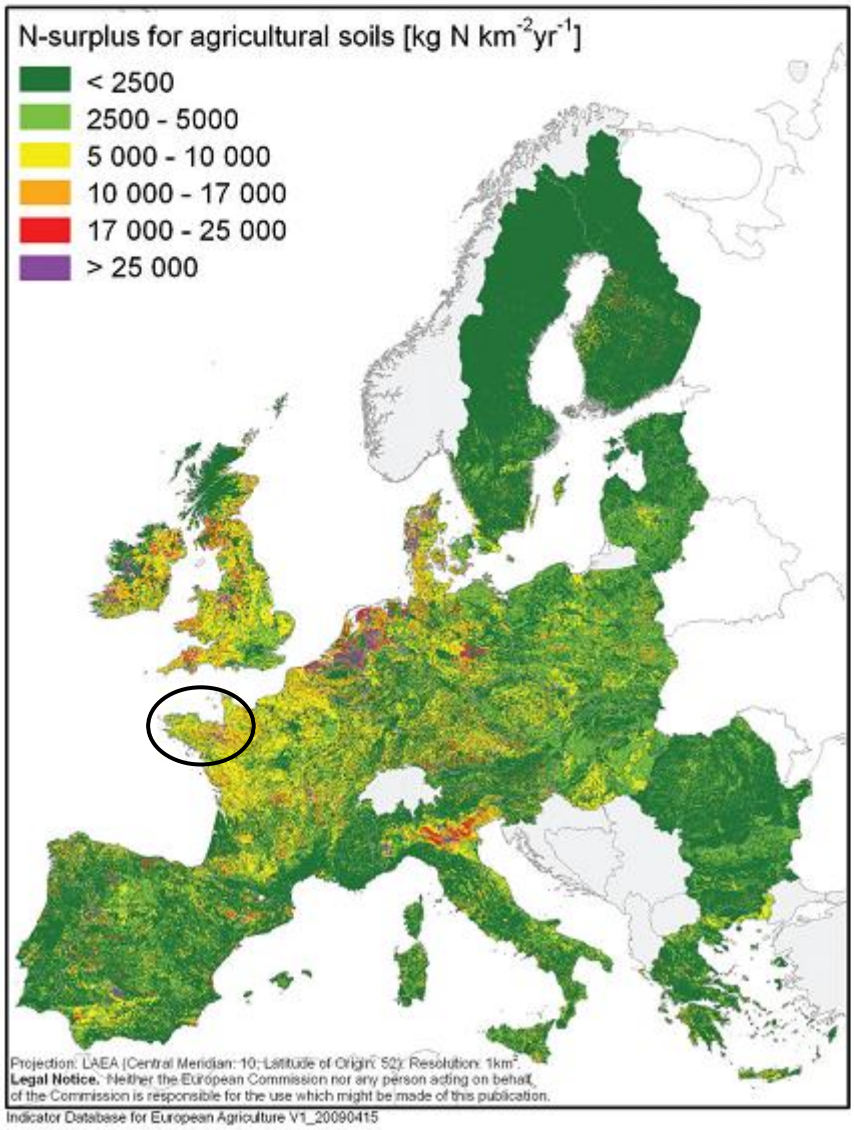

Fig. 8 : "Soil system nitrogen surplus for agricultural soils in EU27 for the year 2002" [41].

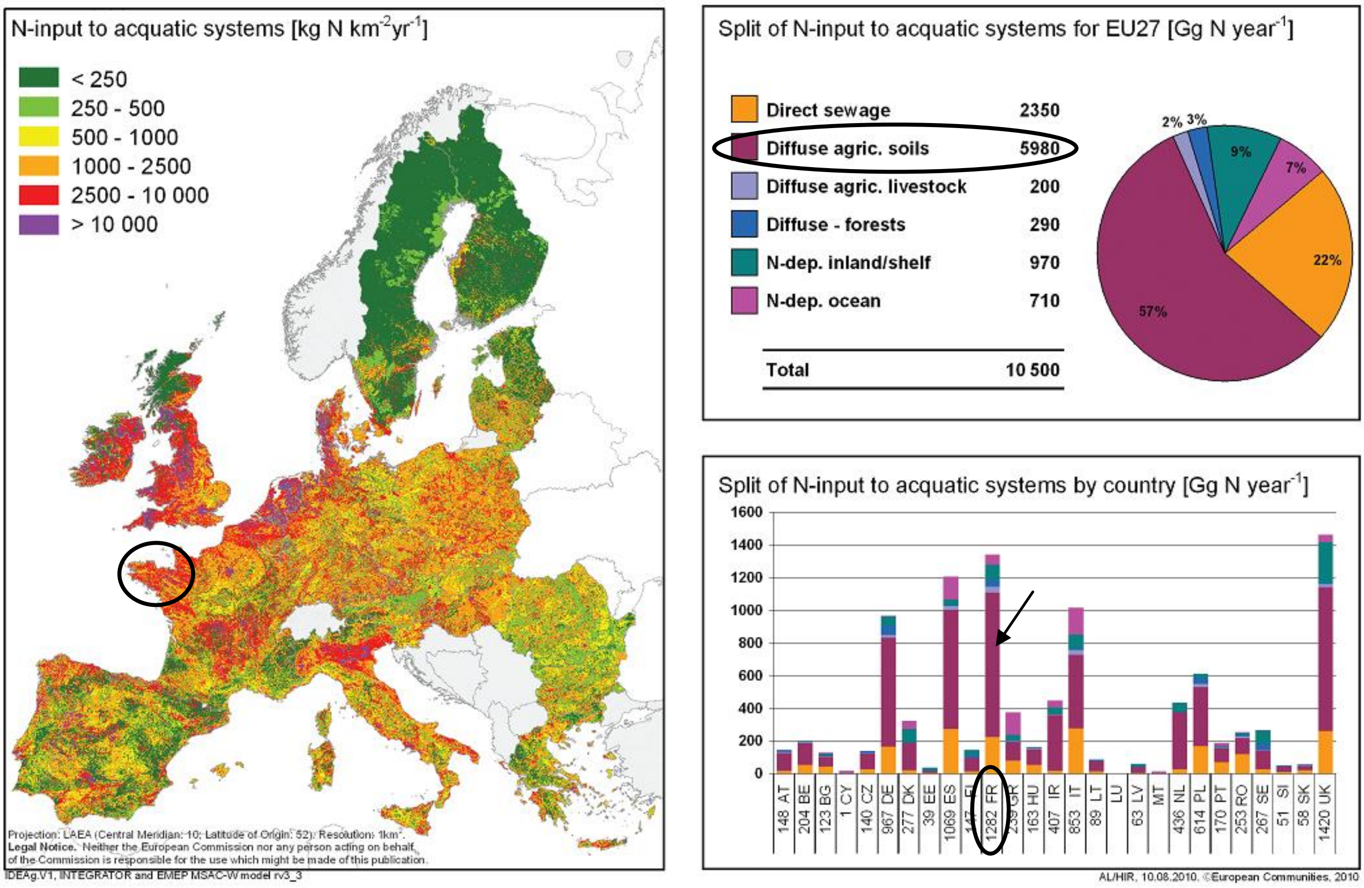

Fig. 9 : "Total reactive N input to the hydrosphere (rivers and groundwater) in EU-27 for the year 2002. The pie diagram at the right side gives the split of N input to the hydrosphere for EU27: The histogram shows the split of N input to the hydrosphere by country." [41].

3. Conclusion

In Brittany, green tides are inducing important troubles since more than 30 years now. Even if real causes are known (agriculture), taken decisions did not really provoke a comeback to a better situation. The monitoring is certainly something difficult and there is always something to say on methods used, especially when too few details are available. A lot of efforts are done since 2002, leading on a precise monitoring that will permit a data comparison in the future. Proliferation annual variations are significant and could only be explained by a huge amount of factors, sometimes difficult to associate. In some cases, we could think that there is a certain stabilisation, but it is too early to be sure. In all case, researchers have without doubt sufficient knowledge on the phenomenon. They can know where efforts have to be done in priority, for instance by focusing on a watershed part [46]. Now it is time to make compromises to take remedies decisions.

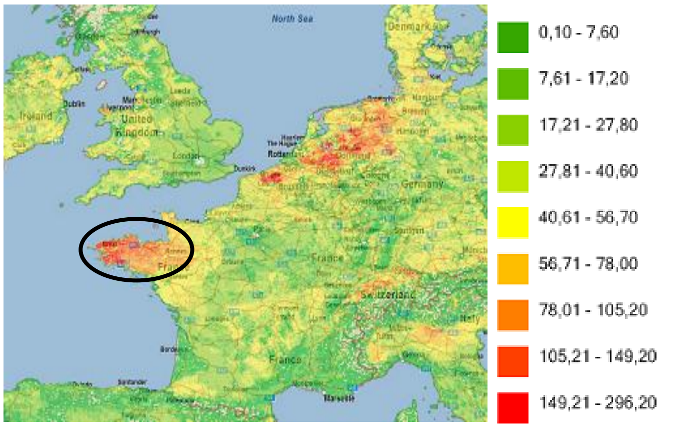

Fig. 10 : Details Ammonia (NH_3) emissions to air from agricultural source (in tones per grid cell). [42].

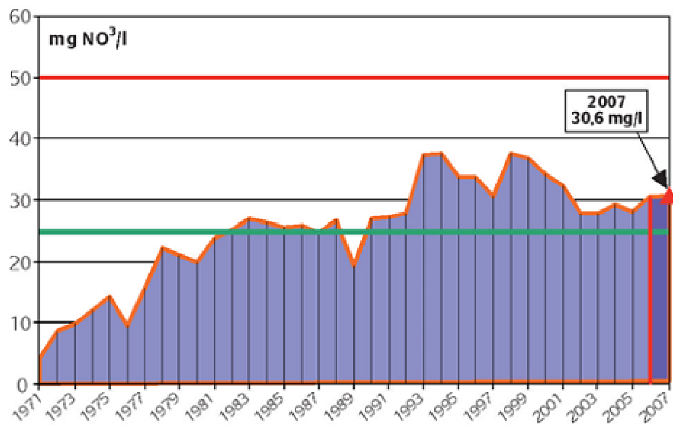

Fig. 11 : Annual average of nitrate concentration in Brittany surface water [43].

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