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Water quality criteria and monitoring for marine mollusc culture: the French experience

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Abstract

The impact of the main parameters of water quality which act on the life history of molluscs are presented. Two types of parameters are examined: the first are the physical-chemical parameters as temperature, salinity, turbidity, oxygen concentrations. They can be modified by perturbations directly related to human activities such as management of physical operations, e.g. constructions of dams, dredging for channels or for extraction of materials. Particular attention is given to inputs of nutrients with as consequences eutrophication and depletion of oxygen causing anoxic conditions. Attention will be focussed on some phytoplankton species like *Gyrodinium aureolum* which can cause mortalities in mollusc shellfish. The action of the main pollutants connected to anthropogenic actions are presented with some examples with heavy metals (mercury, zinc, copper,...) and their synergetic action on larval molluscs. Antifouling substances and the tributyltin story is analysed. The second part of the review will concern the quality criteria necessary to maintain safety conditions for human consumption of products, generally eaten raw. The bacteriological quality is presented as the pollutants contamination. The problems of toxic phytoplankton producing Diarrhetic Shellfish Poisoning (DSP) or Paralytic Shellfish Poisoning (PSP) in humans are analysed. As an example of organization of the monitoring aspects of the water and mollusc quality, the French monitoring is presented with three networks: the National Observation Network of the quality of marine environment (RNO), the phytoplankton monitoring network (REPHY), and the microbiological monitoring network (REMI). Main results and tendencies of these networks will be presented as bases for the definition of an optimum European network for mollusc culture areas.

KEYWORDS: Mollusc culture, Water quality, Monitoring, Networks.

Introduction

Pollutants are acting at different stages of the animal life: in severe concentrations, they can cause adult mortalities and at a lower level modifications in the ethology and physiology of the adults could occur. At these levels recruitment is very often the first function which is submitted to perturbation as the larvae, postlarvae and metamorphosis phases are most sensitive to pollutants. Pollutant action on molluscs will be analysed by identifying the physical parameters in relation with management which can modify the repartition and recruitment of the shellfish population. Then habitat destruction caused by dredging operations as well as by fishing activities will be examined. Eutrophication due to increase in nutrient loadings will be studied in relation to anoxic conditions and the development of macroalgae. Finally, the deleterious effect of pollutants will be analysed (heavy metals and their salts, hydrocarbons, bacterial contamination). The effect of harmful phytoplanktonic bloom in terms of their direct impact of the mollusc population and their negative influence on the consumers will be listed. The French monitoring network is presented as an example of what is applied in a European country.

Water quality criteria for shellfish molluscs

SALINITY EFFECTS

Construction of river dams or barrages for electricity production, mainly to regulate the fresh flux output with retention of waters in winter and use of these waters during summer for agriculture or tourism, modify the salinity regime in estuaries. Some consequences can be important particularly for the survival rate of the larvae and the repartition of the adults. As an example Japanese oysters (*Crassostrea gigas*) require a salinity lower than 34‰ when temperature is under 18°C (Héral and Deslous-Paoli, 1991). Management of the dams must take into account the need for fresh water for the reproduction of marine or estuarine species. On the contrary, during winter, the too intensive fluxes of freshwater increased by deforestation, or by transformation of the marshes for intensive agriculture, cause abrupt decrease of salinity which, when they are frequent, can provoke high mortalities of molluscs (e.g. mussels in Baie de l'Aiguillon or in Baie de Vilaine) (Merceron, 1987).

Furthermore, current and historical data on the distribution of mollusc toxicity along the north coast of the lower St. Lawrence estuary indicate that zones of high Paralytic Shellfish Poisoning (PSP) toxicity are associated with the plumes produced by the rivèr system (Beaulieu and Ménard, 1985; Therriault et al., 1985; Cembella and Therriault, 1988ab; Cembella et al., 1988).

DESTRUCTION OF HABITATS

Several human activities can cause physical damage to benthic communities. Dredging operations mainly comprise: extraction of aggregated and dumping of dredged spoil from estuaries, harbour, mines or sewage. Changes on the sediment chemistry and macrobenthic structure have usually been observed in non dispersive environments. In a recent review on marine dredging for sand and gravel, following the ICES working group on effects on fishes of marine sand and gravel extraction, Mitchell (1989) concluded, that the immediate consequence is the destruction of the benthic invertebrate populations with, eventually, the destruction of spawning or nursery areas. The exposure of anoxic sediments and the turbidity associated with the extraction can modify the ecosystem with perturbation of primary production and meanwhile filtration activity of shellfish. The reintroduction of toxic contaminants has been signalled by Morton (1977) and Johnston (1981), with a number of case studies where elevated levels of toxic gases, organic compounds, and heavy metals have been measured. Even non contaminated sediments can damage the benthic filters by obstruction of gills causing weight loss and after long periods, mortalities.

Dredging in estuaries, in harbour docks, and in the marine environment, to maintain the navigation channel adds a new dimension to the problem previously outlined. The result is a severely modified benthic community with a recovery time exceeding 15 years. These dredged sediments are very often dumped elsewhere at sea, but they are very often highly contaminated by heavy metals (cadmium, mercury, lead, ...) or salts (TBT), or organochlorine (DDT, PCB, ...), and hydrocarbons. Their new availability to the benthic fauna can result in severe contamination. The same problems occurred with the dumping of industrial waste and sewage sludge (Maertens, 1989; Dethlefsen, 1989) which induced a decrease in benthic biomass and the loss of a certain number of species. The same damage is brought about by the construction of trenches for pipelines or cables. Dredging in estuaries can modify riverine biocenoses due to increased mixing and salt water intrusion (Morano et al., 1985) causing modifications.

The destruction of the mollusc population can also be caused by commercial fishing operations. In Chesapeake Bay the use of gears such as patent tongs and dredges contributed to directly modify the oyster habitat by smoothing oyster reefs, reducing their height and even destroying them, inducing higher sedimentation rates and consequently less settlement of spat (Héral et al., 1990; Rothschild et al., 1991). Trawling action with sometimes thicker chains on demersal gears can also cause severe damage to the bottom culture. For the long lines production they are competing for space with the fishermen which with their different gears could cause severe damage to the culture.

EUTROPHICATION

The development of intensive agriculture and the discharge of poorly treated waste waters has resulted in a sharp increase in nutrient input (nitrate, ammonium, phosphorus). Similar to what has been documented in lakes and rivers, the nutrient balance has been modified in estuaries and coastal areas, including closed seas and whole bays function of their hydrodynamic characteristics. The main consequences of such modifications are green macroalgae proliferation and phytoplankton blooms (Menesguen, 1990). Some phytoplankton species producing toxic substances could be indirectly associated with eutrophisation (Smayda, 1990). In Germany under favourable conditions some genera of green algae (*Ulva, Enteromorpha, and Chaetomorpha*) produce an abundant vegetation in areas of intertidal mussel beds. The process of eutrophication is thought to make green seaweeds grow faster in the Waddensea. During summer, the fronds of the algae sometimes twist together. After a few years the algal masses have the appearance of thick green mats which may cover a whole mussel bed. This deprives mussels of water exchange. Further damage results from increased settlement of detritus particles due to reduction of current speed by the great extent of the vegetation. Finally, the decomposition of the accumulated plant masses results in heavy mortality of mussels (Meixner, pers. commun.). In France, in Mediterranean lagoons massive decomposition of algae causes anoxic conditions with destruction of all benthic fauna including cultivated oysters. In French North Brittany where high rise tides induce high velocity currents, the large production of macroalgae does not cause anoxic conditions but massive ground shifts on the beaches which can contribute to the destruction of the benthic fauna in intertidal areas.

ANOXIC CONDITIONS

In summer time during the phytoplankton bloom, their too high biomasses increase the consumption of oxygen. Stratification of the water due to the fresh water input prevents reoxygenation of the bottom water which in addition receives dead cells with high Biological Oxygen Demand. This classical scheme occurs in several places in the world. The examples of Chesapeake Bay and the Baltic Sea are well known. Consequences for benthic organisms are devastating like in Chesapeake Bay where benthic organisms living at a depth greater than 6m are killed, including oyster bars. Only fast growing species which can reproduce all year round are present in such areas when conditions are more favorable (Holland, 1987 in Héral et al., 1990). In France it occurred in Vilaine Bay in 1982 (Merceron, 1987) causing mortality of fish and shellfish. It regularly takes place in the Thau lagoon where this phenomena called "malaïgue" destroys the suspended oyster culture. In New Jersey, Murawski et al. (1989) demonstrated that anoxic water conditions which occurred in 1976 caused mass mortalities of invertebrates particularly surf clams, *Spisula solidissina*, ocean quahog *Arctica islandica*, and sea scallop *Placopecten magellanicus*. Re-population by macrobenthos has been well documented. Two years after the hypoxia were necessary to recover to pre-impact levels of species abundance and diversity. The most significant demersal resources affected were bivalve molluscs. In Kattegat and Skagerrak hypoxia of bottom waters and eutrophication occurred during the 1980's causing damage to mussels, *Mya arenaria* and *Cardium edule* (Engstrom and Fonselius, 1989). In 1988 a bloom of a toxic species *Chrysochromulina polylepis* in this region had deleterious effects on the ecosystem caused as well by the toxic algae as by the depletion of oxygen.

TOXIC PHYTOPLANKTONIC SPECIES

In laboratory experiments *C. polylepis* were found to be toxic to eggs and larvae of the blue mussel *Mytilus edulis* (ICES report edited by Skjoldal and Dundas, 1989). The settlement of *Mytilus edulis* on ropes was low directly after the bloom, but unusually high later in July (Lindahl and Rosenberg, 1989). Benthic organisms and mainly mussels, have been strongly affected by the *C. polylepis* bloom due to direct toxicity of the bloom or to the hypoxia which occurred later in the summer (Engstrom and Fonselius, 1989). Other phytoplanktonic species produce toxins like *Gyrodinium aureolum* which provoked mortality of adult mussels (Tangen, 1977) but also reduced clearance rate causing cellular damage in gut (Widdows et al., 1979), reduced larval survival of *Crassostrea gigas* (Helm et al., 1974), and *Pecten maximus* (Minchin, 1984), and caused mortality in young scallop (Lassus and Berthomé, 1988). Some other species can have different direct effects on shellfish, but it is difficult to make a clear distinction between the direct toxic action and the mortality induced by low oxygen values. It is the case for *Prorocentrum* sp., *Gymnodinium* sp., Gyrodinium sp., *Aureococcus* sp., Ceratium sp., *Cochlodinium* sp., and *Hornellia* sp. (for a review cf. Shumway, 1989).

POLLUTANT ACTIONS

Organotin salt products used in antifouling substances have a deleterious effect on the environment, particularly on molluscs and especially on the Japanese oyster *Crassostrea gigas*. In a review Héral et al. (1989) list the following effects function of the dose:

- acute and chronic toxicity to the adults;
- accumulation in the flesh of the adults;
- perturbation of reproduction particularly fertility, mortality of offspring, and decrease in larval growth rate;
- decrease in the growth rate of adults and thickening of the shell;
- modification of the physiology at sublethal levels.

Regulations have now been put into effect in most European countries and in North America, but they are not always applied for the recreative sailing boats activities.

The chronic input of hydrocarbons has an impact on shellfish life, not limited to the moment of the accident but having far reaching consequences. Groundings of oil tankers such as the Torrey Canyon and the Amoco-Cadiz in 1978 (Brittany, France) or more recently such as Exon Valdey in 1990 (Alaska) have destroyed all the benthic fauna in the immediate vicinity of the grounding. Around the area, depending on wind, wave action, and the characteristics of the oil, the oil dispersed over larger areas, causing accumulation of hydrocarbons in the filter feeders. Some aromatic hydrocarbons could be carcinogen or mutagen (Alzieu and Ravoux, 1989). Furthermore an oil taste remained in the oysters and mussels for a long time compelling local authorities to destroy the surviving oysters. The oil spill from the Amoco Cadiz caused a direct loss of turnover cost evaluated at FF 114 million by 1983 (Bonnieux et al., 1980). In areas of intensive contamination, it has taken more than 10 years to recover a clean sediment. The action of the products used to precipitate the fuel, to disperse it (detergents) was also one of the other factors contributing to the death of the benthos. Other problems may occur. Meixner (pers. commun.) described that mortality and unpleasant smell of mussels was observed some miles off an oil leakage from an oil terminal near Wilhelmshaven. Though a considerable amount of mussels survived the oil spill a total economic loss resulted from the long-lasting bad taste and the ban on mussel harvest imposed by the controlling authorities.

In addition to the human impact, heavy metals can be highly toxic for shellfish. Mortality thresholds have been determined for larvae and juveniles which are the most sensitive stages. The toxicity of cadmium, silver, copper, mercury, zinc, lead and their synergetic action on mollusca have been studied by several authors. For a review, cf. Deslous-Paoli (1982) who classified toxicity levels for shellfish larvae. By order of toxicity the authors found organotin salts, mercury, silver, copper, zinc, nickel, lead, cadmium, chromium, and manganese. McInnes (1981) tested the synergetic effect of copper-mercury-zinc and found that cumulative toxicity was higher by 40 to 60% to that expected.

OTHER ENVIRONMENTAL IMPACTS

Various organic wastes could provoke too high local inputs of organic matter causing anoxic conditions modifying the recruitment of species and causing mortalities in adult populations. It was the case in the Bay of Arcachon where discharge from the local pulp mill seriously modified the oyster production.

Implantation of nuclear power plants near the sea requires large inflow of water for cooling systems comparable with river flow. Aspiration causes destruction mainly of meroplankton compounded by the use of chlorination (1ppm) to fight against fouling. Local warming of water temperature can cause modifications in species repartition, and increase the reproduction of cold species.

Organic wastes and nutrients brought by agriculture have already been mentioned, and in intensive agriculture more and more chemicals (pesticides, weedkillers,...) are being used. In France more than 2 000 products are allowed for agricultural use. The impact of these products on the marine food chain is not known yet.

Aquaculture itself creates its own waste with accumulation of organic matter having severe effects on benthic macro-invertebrates. Directly beneath the culture structures the sediment might become azoic. Due to dispersion, at distances depending on current velocity, proliferation or opportunistic species resistant to organic enrichment have been observed by several authors (for a review see Rosenthal and Rangeley, 1989). These modifications of the bottom occur under mollusc long-lines or rafts with mussels or oysters as well as under fish cages, especially salmonids (Rosenthal et al., 1988).

Human health impact by polluted shellfish

Oysters and mussels being feeders they have the capacity to accumulate live particulate matter such as human pathogenic bacteriae, viruses and toxic phytoplanktonic species. They also concentrate pollutants like heavy metals at levels which can be detrimental to human health.

Bacterial contamination

Even in contaminated areas, pathogenic germs are present in water in small quantities which are difficult to detect and to analyse (Alzieu and Ravoux, 1989).

For this reason, bacterial quality of water is identified by the number of faecal bacteria which are not dangerous for humans but which are very prominent in the sewage. Faecal coliforms and faecal streptococcus are the "test" germs. Salmonella can be looked for in contaminated areas. This requires a tight monitoring particularly of critical points in the vicinity of clams, oyster or mussel beds. The main sources of faecal pollution occur when there is no treatment of the sewage or when sewage-plants are malfunctioning particularly when they are overloaded by summer tourism. Another source may be shuttle service by ferry boats and recreative boats in harbours (Meixner, pers. commun.).

Virus problems

As there is no correlation between enterovirus, viral hepatitis, and the level of test germs, the research of viruses is not taken into account in monitoring the water quality. A risk of catching infective viral hepatitis bound to the consumption of raw molluscs (oysters) exists in areas contaminated by sewage.

Algal biotoxins

Several types of biotoxins affect shellfish, mainly Diarrhetic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP). The marine dinoflagellate *Protogonyaulax tamarensis* has been recognized as the source of Paralytic Shellfish Poisoning (PSP) in Eastern Canadian waters (Needler, 1949). More recently, it has been demonstrated that the diatomea *Nitzschia pungens* was responsible for human amnesic intoxication (ASP, Amnesic Shellfish Poisoning) (Addison and Stewart, 1989). In European countries and in North America, monitoring networks have been generalized since the last 5 years to protect the health of consumers. The different reports of the ICES working group on harmful effects of algal blooms on mariculture and marine fisheries gave the detail of national reports with the occurrences of toxic plankton blooms (ICES, 1989: Report of the working group on harmful effects of algal blooms on mariculture and marine fisheries; ICES 1990: Report of the working group on phytoplankton and the management of their effects).

French monitoring networks

To assure safety conditions of mollusc culture areas, the French Institute of Research (IFREMER) had organized three networks with different aims:

- the monitoring network for marine environmental quality surveillance (RNO) (Joanny, Quintin, Claisse, pers. commun.);
- the phytoplankton monitoring network (REPHY) (Belin, pers. commun.);
- the microbiology monitoring network (REMI) (Miossec, pers. commun.).

RNO (RESEAU NATIONAL OBSERVATION DE LA QUALITE DU MILIEU MARIN)

This network started in 1974-1976 and is still active. It is cofounded by the Ministry of the Environment. The objectives of its actions are:

- to be a useful tool to assess trends and levels of pollutants and general water quality parameters;
- to be a tool for long-term alarm systems;

The periodicity of sampling operations is function of the nature of the sample (water column, living organisms, and sediment).

All the large estuaries are covered for the water column with 11 sectors by winter and summer cruises at a rhythm of 2-5 cruises/year. The number of points covered yearly is 129. For the living organisms the whole littoral is covered with 43 sectors. The sampling rhythm

Table I. Parameters followed by the RNO network for water column, living organisms, and sediments

Components	General quality parameters	Pollutants
Water	Temperature, salinity, pH, oxygen, nutrients (nitrates, phosphates...) particulate matter, chlorophyll	
Living organisms	Species, size, water content, lipids	Metals: mercury, cadmium, lead, copper, zinc
Sediment	Granulometry Organic carbon Loss on heat	Hydrocarbons Organochlorine compounds: lindane, DDT, polychlorinated biphenyls (PCB)

is one each 3 months as the living organisms integrate seasonal variations (Claisse, 1989); 93 samples are taken per year (Fig. 1). For the sediments, 79 samples are analysed once a year as the sediment is integrating annual variations. Estuaries and polluted areas are followed.

REPHY (RESEAU PHYTOPLANCTON)

This network began in 1984 as a result of the presence of the dinoflagellate *Dinophysis* which produced DSP during the summer of 1983-1984 (Berthomé and Lassus, 1985; Belin and Berthomé, 1991).

The objectives of this network are:

- to collect data on phytoplankton populations along the French coast and to provide a very strict monitoring of discoloured waters, blooms, etc.;
- to detect and monitor the presence and development of species toxic for human health and for marine animals.

Thirty-seven surveys are performed systematically throughout the year. The stations are located at regular intervals along the coast, including all the places where shellfish culture is practised. Phytoplanktonic samples are taken twice a month from September to April and once a week from May to August.

Seventy-three warning stations (Fig. 2) are activated when species reputed to be toxic to man have been detected at the station or in the vicinity or if a zone is affected every year by a toxic species.

Phytoplankton countings as well as shellfish analyses are performed as well:

- if a toxic species producing the DSP toxin is present: a mouse-test on a shellfish hepatopancreas extract is used following the protocol of Marcaillou-Le Baut et al. (1985);

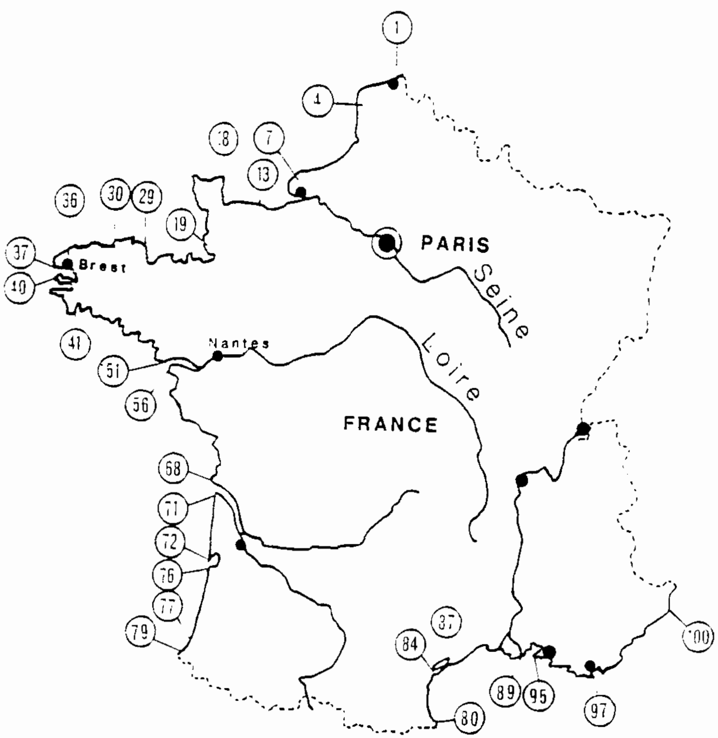

Fig. 1. Sampling sectors of the living animals (oysters, mussels) for the RNO monitoring network.

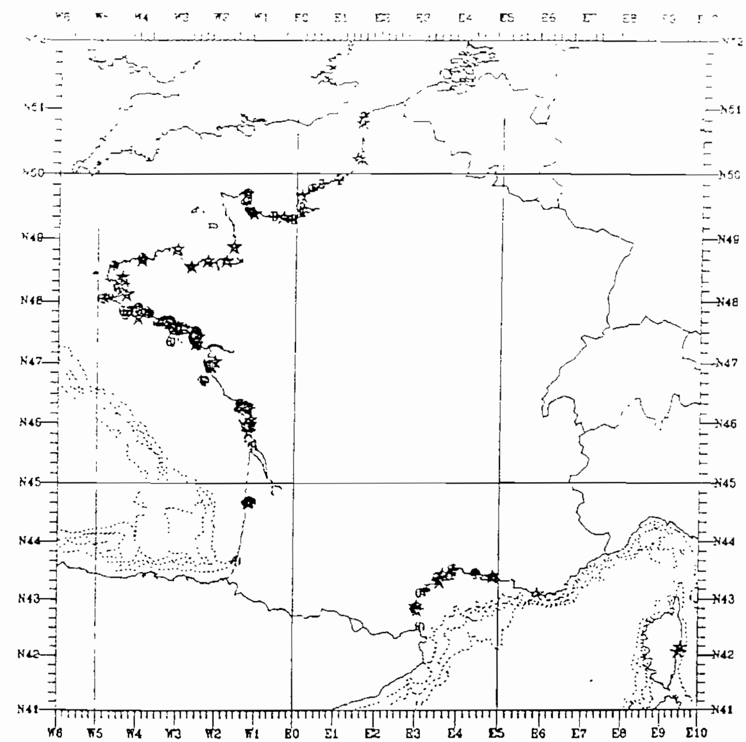

Fig. 2. Survey and warning samples for the REPHY monitoring network.

- if a toxic species producing the PSP toxin is present: a mouse-test is conducted using the AOAC (1984) method.

In the event that suspected toxicity is confirmed by tests, official administrative measures are taken to prohibit the marketing of the shellfish. The ban on shellfish marketing is lifted after two successive negative mouse-tests.

REMI (RESEAU MICROBIOLOGIQUE)

With the future European Economic Community, each country is required to define its shellfish zones for cultivation and to ensure the quality of its production. For these reasons the microbiology network has been founded in 1989 with a routine survey and a warning system. (Miossec and Berthomé, 1991).

The objectives of the routine survey consist in assessing the level and tendencies of bacteriological contamination in the marine environment, measured in shellfish used as integrators. The total coliforms and faecal coliforms are the indicators. Seventy-four hydrological sites are sampled each month with between 2 and 13 stations per site proportionnally to a risk index taking into account previous bacteriological contaminations and the intensity of the mollusc production (Fig. 3).

The objective of the warning system is the protection of the shellfish consumers. The indicators are the total coliforms, faecal coliforms, and Salmonella. Shellfish with breeding zones and marketing activities account for 53 sites (Fig. 4). The minimum warning frequency is weekly or even twice weekly in critical periods. The factors activating this warming system are:

- poor analytic results obtained by the routine survey, veterinary services or other control sources;
- exceptional conditions: pluviometry, storms, low tidal coefficients, agricultural practices, high development of tourism.

Conclusion

After the European Economic Community regulation on the quality of the water for mollusc culture (October, 1979) which gave definitions of good water quality conditions for mollusc culture, the EEC is now preparing a new legislation to standardize the bacterial quality of the molluscs to ensure safe conditions for human consumption. To apply this the European countries will have to monitor the quality of their waters and shellfish with intensive networks. Comparisons of the networks between the different countries, of their parameters, their sampling strategy, their choice of the material (water column, living animals, sediment) need to be done. If possible, a common European network with intercalibrations between the different countries would be suitable, including different specificity of each country and their level of mollusc production.

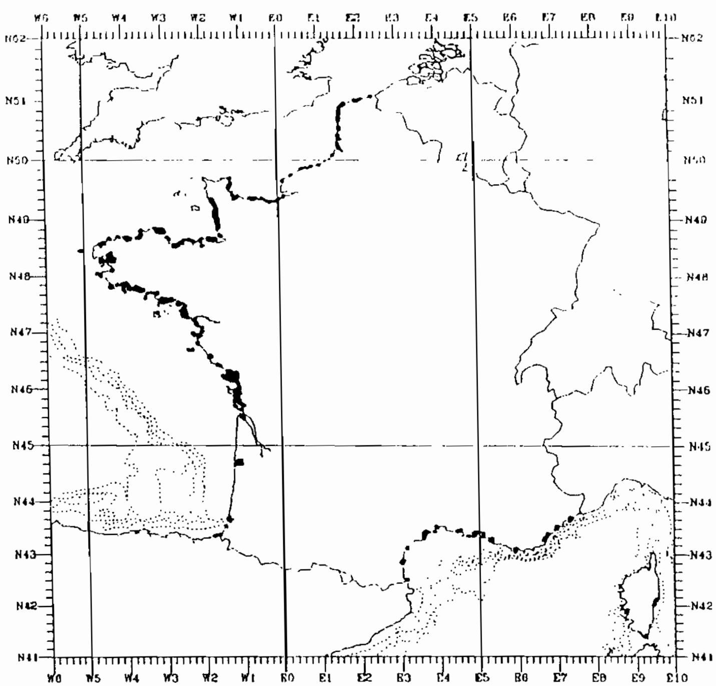

Fig. 3. Routine survey for the REMI monitoring network.

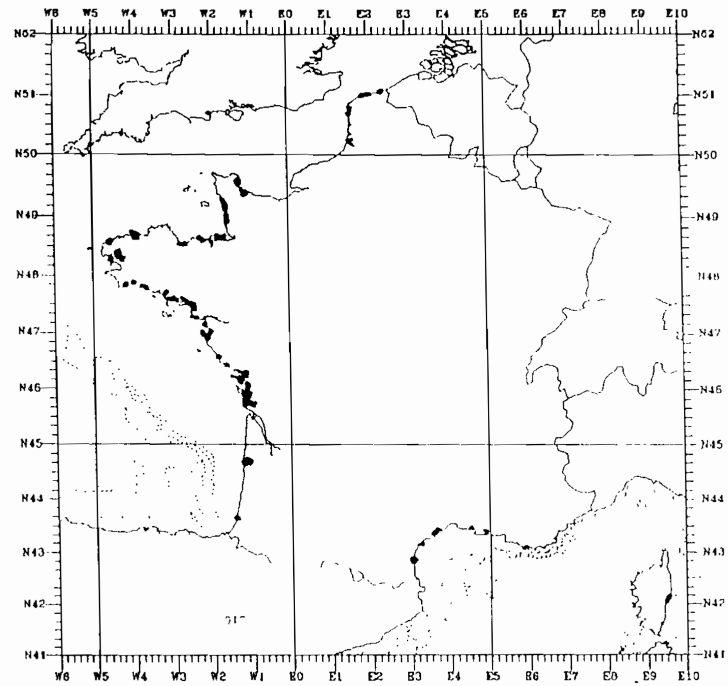

Fig. 4. Warning system for the REMI monitoring network.

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