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POLLUTION OF THE MEDITERRANEAN SEA

Pollution Research and Environmental Monitoring.
Analyses, recommendations and Assessment of the scientific and technological options.

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par

Claude MILLOT, Jean-Pierre BETHOUX et Frédéric BRIAND

1. La Méditerranée - une entité dynamique

Pour l'océanologue, la mer Méditerranée désigne les eaux maritimes de la Méditerranée proprement dite et de golfes et mers qu'elle comprend: la limite occidentale étant le méridien qui passe par le phare du Cap Spartel (à l'entrée du détroit de Gibraltar), et la limite orientale étant constituée par la limite méridionale du détroit des Dardanelles.

Etymologiquement "mer située au milieu des terres", la Méditerranée constitue une entité dynamique et climatique. Sa forme et la profondeur de ses bassins résultent des mouvements de l'écorce terrestre (tectonique des plaques, échelle de temps: le million d'années) et de l'évolution du climat. Ses caractéristiques physiques, chimiques, biologiques et climatiques dépendent de ses échanges avec l'Atlantique, l'atmosphère et les continents qui la bordent. Ses échanges avec la mer Noire à travers les détroits des Dardanelles et du Bosphore (seuil à 40 m de profondeur) sont particulièrement critiques sur un plan environnemental, compte tenu du dramatique degré de dégradation de cette mer sous l'impact de l'homme. Les caractéristiques physico-chimiques de la Méditerranée ne sont donc pas immuables.

A titre d'exemple, depuis le dernier épisode glaciaire (il y a environ 20000 ans) le niveau de la mer est remonté de -120m jusqu' au niveau actuel, la salinité a baissé de deux unités et la température a augmenté de 5°C. Ces dernières grandes fluctuations résultaient de causes "naturelles", principalement de légères modifications de l'orbite de la terre autour du soleil. Actuellement, il est à craindre que les activités humaines induisent des variations du climat et de l'environnement beaucoup plus rapides puisque déjà perceptibles dans le bassin Occidental.

2. Le fonctionnement climatique de la Méditerranée

Mer profonde (en moyenne 1500m, mais atteignant jusqu'à 5100m en mer Ionienne), elle est reliée à l'océan Atlantique par le détroit de Gibraltar dont le seuil n'est situé qu'à environ 300m de profondeur. A ce détroit se superposent deux courants de sens inverses: un courant atlantique superficiel entrant et un courant mediterranéen profond sortant. Cette particularité, connue depuis longtemps par les navigateurs, a fait l'objet d'une incitation de recherche de la "Royal Society" de Londres en 1661 et c'est en 1755, devant l'Académie Royale des Sciences de Suède que J.S.Von Waitz en donna une première explication scientifique prenant en compte les effets de l'évaporation.

En moyenne annuelle l'évaporation est de l'ordre de 1,5m, tandis que les apports d'eau douce par les précipitations et les cours d'eaux constituent une couche de 0,5m/an. Le bilan en eau douce est donc négatif, il entraîne une augmentation de la salinité et explique l'existence des flux superposés et opposés au détroit de Gibraltar, un excès d'eau atlantique entrante sur l'eau méditerranéenne sortante équilibre le bilan en eau (voir Figure).. Sans cette compensation, le niveau de la mer baisserait d'un mètre chaque année.

Ces processus qualifient un fonctionnement en bassin de concentration dont la mer Rouge constitue un deuxième exemple. Un exemple inverse est donné en Baltique et en mer Noire, qualifiées de bassins de dilution, où l'excès des précipitations et des apports des fleuves sur l'évaporation entraîne la sortie superficielle d'eaux peu salées et l'entrée profonde d'eaux plus salées. Ces exemples illustrent la forte relation entre le climat et la circulation marine.

L'évaporation constitue également une perte thermique pour la mer (chaque cm^3 ou gramme d'eau évaporée représente la perte de 2400 joules) et un gain pour l'atmosphère où cette même énergie est stockée, puis libérée lors de la condensation de la vapeur d'eau. Le bilan d'eau douce négatif de la Méditerranée indique que la chaleur et l'eau perdues par cette mer sont en partie transférées hors du bassin méditerranéen et contribuent à la circulation atmosphérique de l'hémisphère nord. C'est un deuxième exemple d'interaction entre la mer et l'atmosphère.

3. La circulation générale

Le déficit en eau de l'ensemble du domaine méditerranéen est comblé par l'entrée d'eaux océaniques dont les caractéristiques hydrologiques vont être progressivement modifiées par suite des interactions avec l'atmosphère et du mélange avec les eaux résidentes.

Lorsque les conditions météorologiques hivernales sont particulièrement rigoureuses, des phénomènes complexes, se développant dans les parties septentrionales de la Méditerranée (le golfe du Lion et la mer Ligure, l'Adriatique et la mer Egée), là où pénètrent des masses d'air froid provenant des régions polaires, entraînent une augmentation de la densité des eaux superfielles qui plongent alors à des profondeurs plus ou moins grandes. Cette formation hivernale d'eaux profondes, qui constitue l'un des moteurs de la circulation marine, ne se retrouve qu'en de rares régions océaniques: dans les océans polaires Arctique et Antarctique et en mer Rouge.

La Méditerranée transforme ainsi les eaux océaniques en eaux toujours plus salées et généralement plus froides, dont les caractéristiques dépendent des bassins dans lesquels elles ont été formées; ces eaux typiquement méditerranéennes vont ensuite se mélanger plus ou moins parfaitement et s'écouler dans l'océan où elles peuvent être individualisées jusqu'à des milliers de kilomètres. Les profondeurs relativement faibles du détroit de Gibraltar et du canal de Sicile, ainsi que le sens pratiquement unique de l'écoulement des eaux de surface dans ces passages, impliquent des différences fondamentales dans le devenir des divers types de polluants: les produits qui flottent ou coulent resteront définitivement piégés en Méditerranée, tandis que les produits dissous se répandront en quelques décennies ou siècles dans l'océan.

Caractéristiques hydrologiques de la Méditerranée

BILAN D'EAU MOYEN			
En entrée		En sortie	
de l'Atlantique	35 000	évaporation	3 500
de la mer Noire	200	dans l'Atlantique	32 900
précipitations	850		
des fleuves	350		
Total	36 400	Total	36 400

Les volumes sont exprimés en kilomètres cubes/ an

Par ailleurs, la rotation de la terre tendant à déplacer sur la droite toutes les masses en mouvement dans l'hémisphère nord, la circulation générale des eaux dans un bassin fermé va se faire le long de la topographie dans le sens inverse de celui des aiguilles d'une montre. Schématiquement, les eaux entrantes, donc relativement légères, vont ainsi faire le tour de chaque bassin en longeant d'abord les côtes sud avant de se diriger vers le nord où elles arriveront avec une densité accrue. La stratification, qui est défavorable à la diffusion verticale, entre les eaux entrantes et résidentes (interface permanente vers 100-200 m), est donc généralement plus marquée au sud qu'au nord des bassins. Dans la couche de surface, cette stratification est aussi plus marquée en été (thermocline saisonnière à quelques dizaines de mètres) qu'en hiver. Ceci est plus particulièrement le cas dans certaines régions nord, généralement à plusieurs dizaines de kilomètres des côtes, là où une partie des eaux de surface est définitivement transformée en eaux plus denses; la stratification hivernale extrêmement réduite et les phénomènes de plongée, qui intéressent toute ou partie de la hauteur d'eau, vont alors favoriser la pénétration en profondeur des polluants dissous.

Ces conditions météorologiques et hydrologiques, ainsi que la nature des processus hydrodynamiques qui se développent, conditionnent directement les caractéristiques de la circulation des eaux dans et entre les différents bassins. Sur la base d'un nombre important d'observations hydrologiques (des milliers de profils verticaux), d'enregistrements courantométriques (des centaines de séries temporelles d'une durée de plusieurs mois) et de données satellitaires (des centaines d'images dans l'infrarouge thermique) collectés en Méditerranée occidentale, Millot (1991) a pu présenter une description cohérente des caractéristiques de la circulation générale.

Schématiquement, on peut considérer que les régions sud des différents bassins sont le siège d'une turbulence à moyenne échelle très intense: la circulation des masses d'eau est fortement conditionnée par la présence de tourbillons d'un diamètre de 50 à 200 km et d'une durée de vie de plusieurs mois, voire un an et plus. Au nord, la circulation est plus stable: elle s'écoule le long de la topographie, autour des zones du large moins stratifiées dont certaines sont le siège des formations hivernales d'eau dense. Le transport des polluants depuis les zones côtières vers le centre des bassins est donc généralement limité au nord et facile au sud.

Cette circulation générale est caractérisée, tant au sud qu'au nord, par des vitesses de plusieurs dizaines de kilomètres par jour et une extension verticale de plusieurs centaines de mètres qui lui fait suivre la pente continentale. Notons cependant que, le long de cette pente, le sens du courant moyen (sur quelques jours) est toujours le même au nord alors qu'au sud, à cause des tourbillons mentionnés au paragraphe précédent, il peut être inversé pendant des mois. Même là où la circulation est relativement stable, comme dans les régions nord, elle est perturbée par des instabilités qui prennent la forme de méandres (quelques dizaines de kilomètres, quelques jours) de plus ou moins grande amplitude; la circulation n'a donc pas toujours la même incidence par rapport à la topographie. De plus, elle engendre, par frottement avec cette topographie qui est généralement très rugueuse (canyons), des turbulences de relativement petite échelle (quelques kilomètres, quelques jours) qui intéressent une bande côtière de plusieurs kilomètres de large. Toutes les zones côtières apparaissent ainsi plus favorables à la dilution des polluants qu'à leur transport sur de grandes distances.

D'après l'analyse précédente, il apparait que l'entraînement de la couche de surface par le vent (courant de dérive) ne joue pas un rôle prépondérant dans la circulation générale. Il est évident, tant d'après les observations que des modèles réalistes (qui, par exemple, ne sont pas forcés par des vents mensuels), que l'action du vent dépend étroitement de sa durée. Elle dépend aussi beaucoup de la stratification: en milieu homogène, l'énergie se propage en profondeur et n'entraîne pas de dérive significative, tandis qu'en milieu stratifié et au large, l'entraînement de la couche mélangée de surface (quelques dizaines de mètres) est généralement notable. Ceci étant, la durée relativement faible des vents forts (quelques jours), leur extension souvent limitée à quelques centaines de kilomètres, et les contraintes imposées par la topographie, font que la circulation générale dépend sans doute peu de la tension du vent. Par contre, l'action du vent dans les échanges thermohalins entre l'océan et l'atmosphère est fondamentale pour la circulation des eaux de surface, comme l'ont montré des observations (Astraldi et Gasparini, 1992) et des modèles analytiques (Crépon et al., 1989) et numériques (Madec et Crépon, 1991) sur la variabilité saisonnière de la circulation dans le nord des bassins. Il faut également considérer que le vent peut être le principal facteur intervenant dans le transport des pollutions superficielles (nappes d'hydrocarbures) et que, compte tenu de la prédominance des vents de nord à nord-ouest, les côtes sud et est sont généralement plus exposées que les côtes nord et ouest.

La facilité relative de campagnes océanographiques hivernales en Méditerranée a fait que cette mer a constitué dans les années 1960 et 70 une zone-test internationale d'étude des processus de formation d'eau profonde (réf.Medoc Group,1970). La formation hivernale d'eaux denses favorise le transfert vertical des éléments chimiques de la surface vers la couche profonde, et l'existence de seuils peu profonds aux détroits de Sicile et de Gibraltar favorise l'homogénéïsation des concentrations dissoutes dans la couche profonde. Conséquence du fonctionnement en bassin de concentration, en Méditerranée Occidentale, on calcule un temps de résidence des eaux profondes ou temps de renouvellement des eaux , quotient du volume du bassin par le flux entrant ou sortant, de seulement 15 ans environ (alors qu'il est de l'ordre du millénaire dans les grands océans). En première approximation, les caractéristiques des eaux profondes reflètent donc les conditions climatiques moyennes (ou l'état géochimique moyen) des 15 dernières années.

4. Une zone vulnérable

Ne représentant que 0,7% de la superficie marine de la planète, la Méditerranée est traversée par près de 40% du trafic maritime pétrolier mondial. Les populations des nations côtières, en forte expansion démographique sur la rive Sud, représentent 4,3% de la population mondiale. Le Bassin en outre attire plus de 120 millions de touristes saisonniers chaque année sur ses côtes, soit 50% du tourisme mondial.

5. Conventions internationales pertinentes

Territorial waters usually extend to 12 nautical miles. In certain cases a fishing zone has been extended to 15 miles (Albania, Lybia, Morocco,Tunisia), and even 20 miles (Malta). There is no Exclusive Economic Zone (EEZ) in the Mediterranean Sea, due to the special geographic configuration and resulting potential overlaps. As a result, many areas of the Mediterranean Sea are considered as international waters regulated by relevant international treaties and conventions. These texts are quite thorough on paper; but their efficiency leaves much to be desired due to a lack of adequate tools and political will for their proper application and enforcement .

5.1 -The Barcelona Convention (1976)

The Convention for the Protection of the Mediterranean Sea, signed in Barcelona in February 1976, was the first convention on regional seas adopted under the aegis of the United Nations. Il is a framework convention: any contracting State must concurrently become a party to at least one of its protocols. To date four protocols have been adopted:

- protocol for the protection of the Mediterranean Sea by dumping from ships and aircraft (Barcelona, 1978);
- protocol concerning cooperation in combatting pollution of the Mediterranean Sea by oil and other harmful substances in case of emergency (Barcelona, 1978);
- protocol against pollution from land-based sources (Athens, 1980);
- protocol concerning Mediterranean specially-protected areas (Geneva, 1982).

It is widely recognized that the Barcelona Convention is not properly enforced in most, if not all, contracting parties.

5.2 - MARPOL 73 / 78

This Convention, managed by IMO, is designed to prevent pollution by operational discharges from ships. It comprises five annexes which deal respectively with oil, bulk chemicals, chemicals in packaged form, sewage and garbage. This instrument, along with the one mentioned below, is the only international treaty now in force, which deals with marine pollution on a global scale.

This Convention recognizes the Mediterranean Sea as a special area, where petroleum discharges from ships are prohibited.

The entry into force of this Convention in 1983 had a substantial positive impact in decreasing within two years by 60% the amount of oil entering the sea from maritime transportation activities. This is further evidenced by a significant reduction in beach tar around the world since 1979 (*source* : 1990 GESAMP Report)

Unfortunately, 10 years after its implementation, there is now widespread evidence of a lack of worldwide enforcement of MARPOL. As noted by a recent (1991) report of the

US National Academy of Sciences:

- there is a lack of worldwide efficient monitoring;
- there is difficulty in identifying the source of oil spills;
- there is a lack of worldwide port state control systems.

Further, an 1992 evaluation by the Dutch agency AIDEnvironment concluded that most contracting parties to MARPOL did not fully comply with the articles of the Convention.

With respect to the Mediterranean Sea, it is broadly suspected that this convention is largely violated : one thinks in particular of the large amounts of oil deliberately discharged in the southeastern part of the Basin.

5.3 - *The London Dumping Convention (1972)*

This Convention, for which IMO is also responsible, is aimed at minimizing pollution from dumping of wastes at sea.

5.4 - *Convention on Biodiversity (Rio de Janeiro, 1992)*

This Convention, recently signed in Rio by most countries - with the noted exception of the USA - imposes a general obligation to protect habitats particularly rich in biodiversity. Certain areas of the Mediterranean Sea certainly fall in this category, with their high degree of endemism and high vulnerability. The Convention mentions without details the need for funding mecanisms to assist developing countries in its application.

5.5 - *Law of the Sea Treaty (1982)*

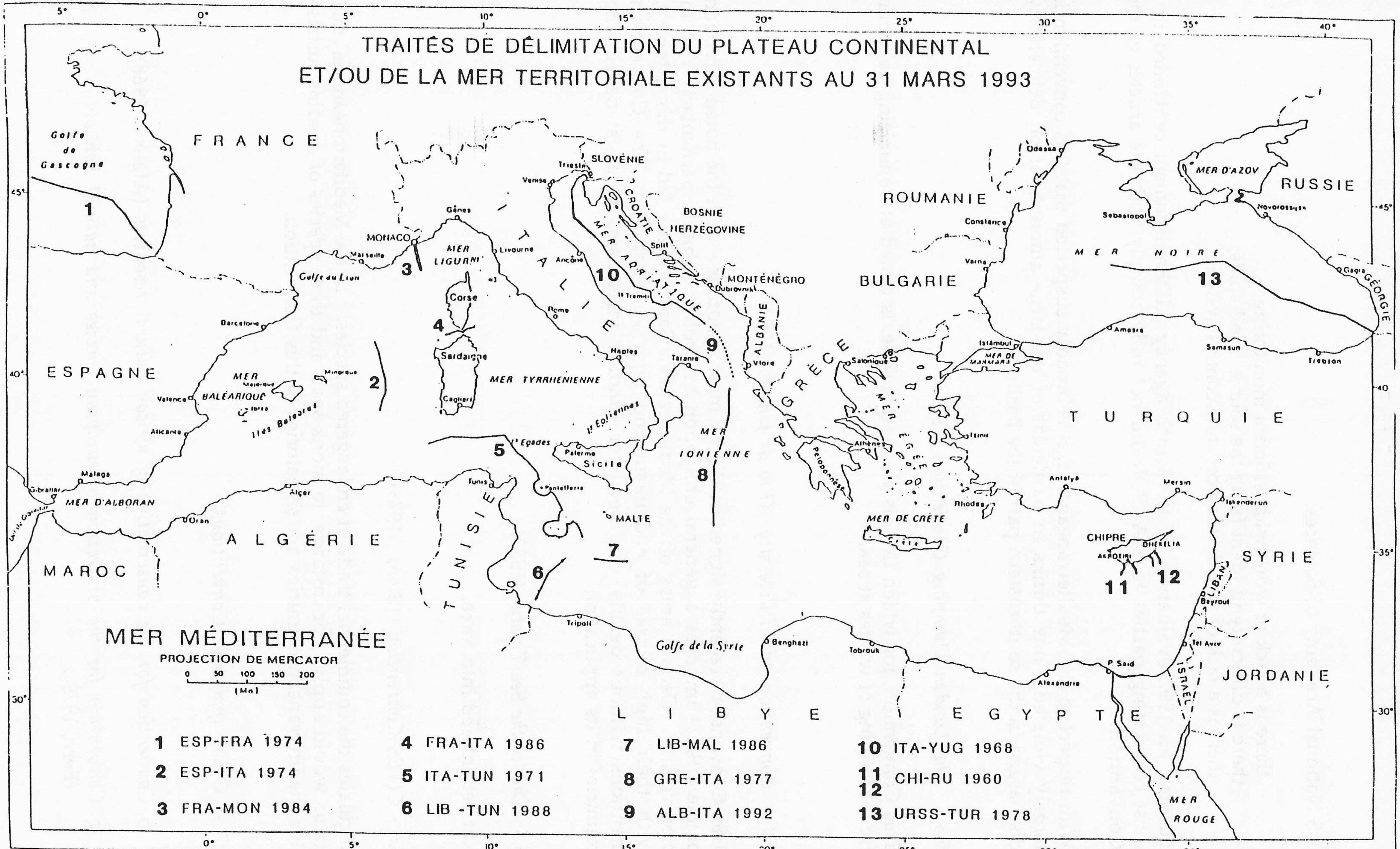
Not yet entered into force.

5.6 - *CITES Convention (Bonn , 1973)*

Regulates the commercial trade of endangered species. In the Mediterranean sea this status would apply, for instance, to monk seals and three species of marine turtles. Five mediterranean countries are signatories to this Convention.

5.7 - *Other applicable Conventions*

- o *Convention for the conservation of african natural resources* (Algiers, 1968);
- o *Convention for the protection of european species and natural habitats* (Bern, 1979);



Les dates sont celles de la signature des traités o *Convention for the conservation of wetlands of international importance* (Ramsar,1971):

Aims to protect wetland areas of extreme ecological importance, particularly for the routes of migratory birds, which figure on a world list. This list now includes more than 60 coastal sites. In 1990 a special Trust Fund was created to assist developing countries in the application of the Convention. Ten mediterranean countries are signatories.

Mediterranean coastal wetlands are most important for maintening biodiversity, controlling floods and cleansing polluted waters. These are usually quite productive systems, playing a substantial role in the local economy with such developments as aquaculture or rice production.

5.8 - RAMOGE

A tri-partite subregional convention, signed in 1976 between France, Italy and Monaco, to better integrate national efforts against coastal pollution - with respect to monitoring, research and planning - in a zone extending originally from Saint-Raphaël to Genoa.

The area covered by the Convention has now been enlarged to Marseille in the West, and to La Spezia in the East. This is the first convention of its kind. A similar coastal protection treaty is about to be signed between the provinces of Catalunya (Spain) and Languedoc-Roussillon (France).

5.9 - Non-constraining Declarations

o *Genoa Declaration* (September 1985)

Was adopted by the contracting parties to the Barcelona Convention; it proposed various objectives for the period 1985-1995, and, in particular, the identification and protection of at least 50 new coastal natural sites.

o *Nicosia Charter* (April 1990)

Adopted by the Environment Ministers of the mediterranean countries, it lists priority actions for environmental protection, including the identification and sustainable management of coastal sensitive areas.

6. Zones de responsabilité

Si aucune zone économique exclusive n'a été déclarée en Méditerranée, il existe en revanche plusieurs traités bilatéraux de délimitation du plateau continental. La Figure montre les lignes de délimitations qui y ont été agréés jusqu'à présent (1993). Ces lignes pourraient être utilisées pour indiquer aux nations concernées les limites de leurs responsabilités en ce qui concerne la protection du milieu marin et pour les encourager à établir des accords bilatéraux de coopération opérationnelle de lutte contre la pollution, du type de l'Accord Ramoge.

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II - BILAN PHYSICO-CHIMIQUE ET BIOLOGIQUE

La Méditerranée, témoin d'évolution du climat et de l'environnement

par Jean-Pierre BETHOUX

Laboratoire de Physique et Chimie marines, CNRS, B.P. 8, 06230-Villefranche sur Mer, France

1. Evolution climatique

Les mesures réalisées en 1988 et 1989 lors des campagnes MEDATLANTE (programme JGOFS-France) à bord du navire océanographique Jean Charcot et l'analyse des données historiques de différentes campagnes faites au cours de la période 1959-1987 montrent un échauffement quasi continu de la couche d'eau profonde du bassin Occidental qui a atteint 0,12°C au cours des 30 dernières années (Figure 1). Cet échauffement est accompagné d'une augmentation de la salinité, d'environ 0,03 psu (unité de salinité) (BETHOUX et *al.*,1990a). Se trouvent ainsi confirmées les premières présentations d'évolution de température et salinité de CHARNOCK (1989). L'eau profonde du bassin Occidental résulte du mélange hivernal d'eau de surface et d'eau intermédiaire, cette dernière provenant des eaux profondes orientales, après passage par le détroit de Sicile.

Dans l'hypothèse défendue par BETHOUX et *al.* (1990a), l'élévation de température des eaux profondes occidentales provient de celle des eaux superficielles lors de la formation hivernale d'eaux denses et donc relève d'une modification faible mais continue du climat à la surface de la Méditerranée. L'augmentation de salinité résulte alors d'une variation du bilan en eau, à savoir augmentation de l'évaporation suivant celle de la température superficielle et diminution des précipitations observée sur toute la Méditerranée, un deuxième signe de changement climatique (Fig.2).

Dans l'hypothèse proposée par LEEMAN et SCHOTT (1991) et reprise par ROHLING et BRYDEN (1992), l'augmentation de température des eaux du bassin Occidental résulterait, via la formation d'eau dense, de l'augmentation de salinité de l'eau intermédiaire. Celle ci serait liée à une modification du bilan en eau du bassin Oriental résultant notamment de la forte réduction du débit du Nil à la mer depuis la fermeture du barrage d'Assouan en 1964, ainsi que des apports des fleuves russes tributaires de la mer Noire.

Dans ces deux hypothèses, les modifications des caractéristiques température et salinité des eaux profondes du bassin Occidental résultent des activités anthropiques, soit un effet direct de la consommation d'eau douce sur les apports des fleuves à la mer, soit un effet indirect de la pollution atmosphérique par les gaz à effet de serre. L'exploitation du signal marin d'évolution des caractéristiques physiques de la Méditerranée est importante non seulement pour en déceler la cause mais encore pour pouvoir prévoir l'évolution du système.

1.1 - hypothèse d'une conséquence de l'augmentation de l'effet de serre

Depuis la constatation de l'augmentation de la concentration de gaz carbonique, directement liée à celle de la consommation d'énergie fossile, les calculs des climatologues pronostiquent un échauffement du climat (voir par exemple LETREUT,

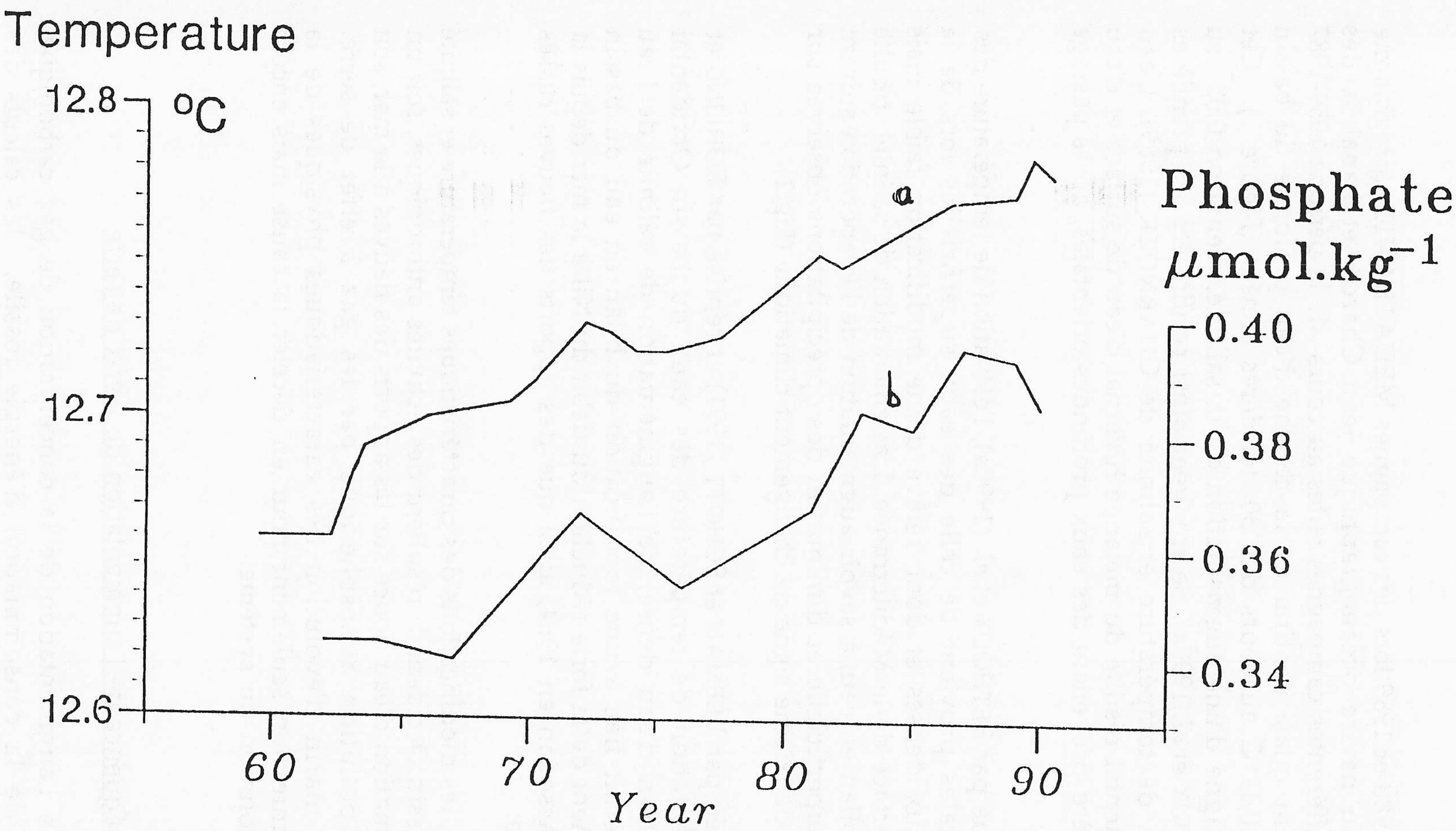

Figure 1, courbe a: Evolution de la température potentielle dans l'eau profonde du bassin Algéro-provençal, température moyenne de la couche comprise entre 2000m et le fond (jusque vers 2700m). L'échauffement (0,12°C sur les trente dernières années) et l'augmentation concomitante de la salinité (0,03 psu) indiquent un changement des bilans en chaleur et en eau à travers la surface marine, donc une probable évolution climatique.

courbe b: Evolution de la concentration en phosphate des eaux profondes du bassin Algéro-provençal. L'augmentation de la concentration moyenne de la couche 400m-fond prouve l'augmentation des apports telluriques et de la productivité biologique dans la couche de surface et de la consommation d'oxygène en profondeur.

1991). On a tenté de déceler, tant à la surface de la terre que dans les océans, un signal d'élévation des températures. A l'échelle mondiale, il apparaît depuis le début du siècle une augmentation moyenne de la température de l'air de près de 0,5°C (JONES et *al.*, 1988). Dans les océans, où les mesures sont bien moins nombreuses, le transport de chaleur par les courants marins est un terme important et variable qui masque de faibles variations locales du bilan thermique à travers la surface et, à ce jour, n'apparaît aucun signal net d'échauffement.

En Méditerranée, l'advection thermique par le détroit de Gibraltar étant faible, tout changement de température de l'épaisse couche homogène d'eau profonde est, a priori, lié à une modification climatique. Une modélisation des transferts thermiques à partir des flux d'eau entre les deux bassins et de la formation d'eaux profondes (BETHOUX, 1980) permet de relier la variation mesurée de température des eaux profondes (0,12°C sur 30 ans, soit environ 4×10^{-3}°C/an) à une variation calculée de la température de surface de l'ordre de 20×10^{-3}°C/an (soit 0,6°C sur 30 ans; BETHOUX et *al.*, 1990a). Par suite de la forte variabilité spatio-temporelle de la température de la couche de surface, une telle variation n'y est pas encore décelée.

L'évolution de la température de toute la colonne d'eau correspond à une modification du bilan thermique de la mer de +1 Watt/m^2. Ceci peut résulter d'une faible augmentation des apports d'énergie à la mer et/ou d'une faible diminution des pertes vers l'atmosphère(qui s'élèvent chacune à environ 200 Watt/m^2). L'apport principal d'énergie, l'éclairement solaire, peut être supposé constant sur les trente dernières années, et la modification envisageable de la température des eaux atlantiques, de l'ordre de celle de la température de l'air à l'échelle mondiale, ne produirait qu'une modification du flux thermique à Gibraltar très inférieure à 1W/m^2.

Evaporation, convection et rayonnement propre de la mer sont directement proportionnels à la température de l'eau. L'échauffement de la couche de surface, loin de pouvoir résulter d'une diminution de ces transferts, ne peut donc produire que leur augmentation; l'échauffement ne peut donc résulter que d'une augmentation du rayonnement infra-rouge de l'atmosphère. Ce dernier dépend de la température de l'air et des constituants qui absorbent dans le domaine infra-rouge, principalement la vapeur d'eau, le gaz carbonique et le méthane. L'augmentation constatée de la concentration atmosphérique en gaz carbonique a permis le calcul, à partir de modèles atmosphériques, d'un probable effet de serre, surplus d'émissions infrarouge de l'atmosphère, de 2 W/m^2 (voir par exemple J.F.B MITCHELL, 1989). Le bilan thermique de la Méditerranée permet également, à partir de l'augmentation constatée de température des eaux et d'hypothèses sur celle de la température de l'air, de calculer un effet de serre de 2 W/m^2 qui se traduirait pour moitié par un échauffement des eaux et pour moitié par une augmentation des échanges mer-air par évaporation et convection. L'échauffement, faible, des eaux profondes occidentales ne doit pas encore avoir d'incidence sur l'écosystème. Par contre, dans la couche de surface, où il devrait être cinq fois plus fort, il pourrait rapidement favoriser l'installation de nouvelles espèces tropicales. Par ailleurs, la dilatation thermique des eaux doit déjà se traduire par une élévation moyenne du niveau de la mer de l'ordre de 4 cm au cours des trente dernières années.

En Méditerranée, le signal de modification climatique est relativement facilement accessible par les techniques océanographiques (profils verticaux de bathysonde mesurant avec une grande précision la température, la salinité et la profondeur); cette mer constitue donc un lieu privilégié d'études climatiques et peut-être une première preuve de l'augmentation de l'effet de serre.

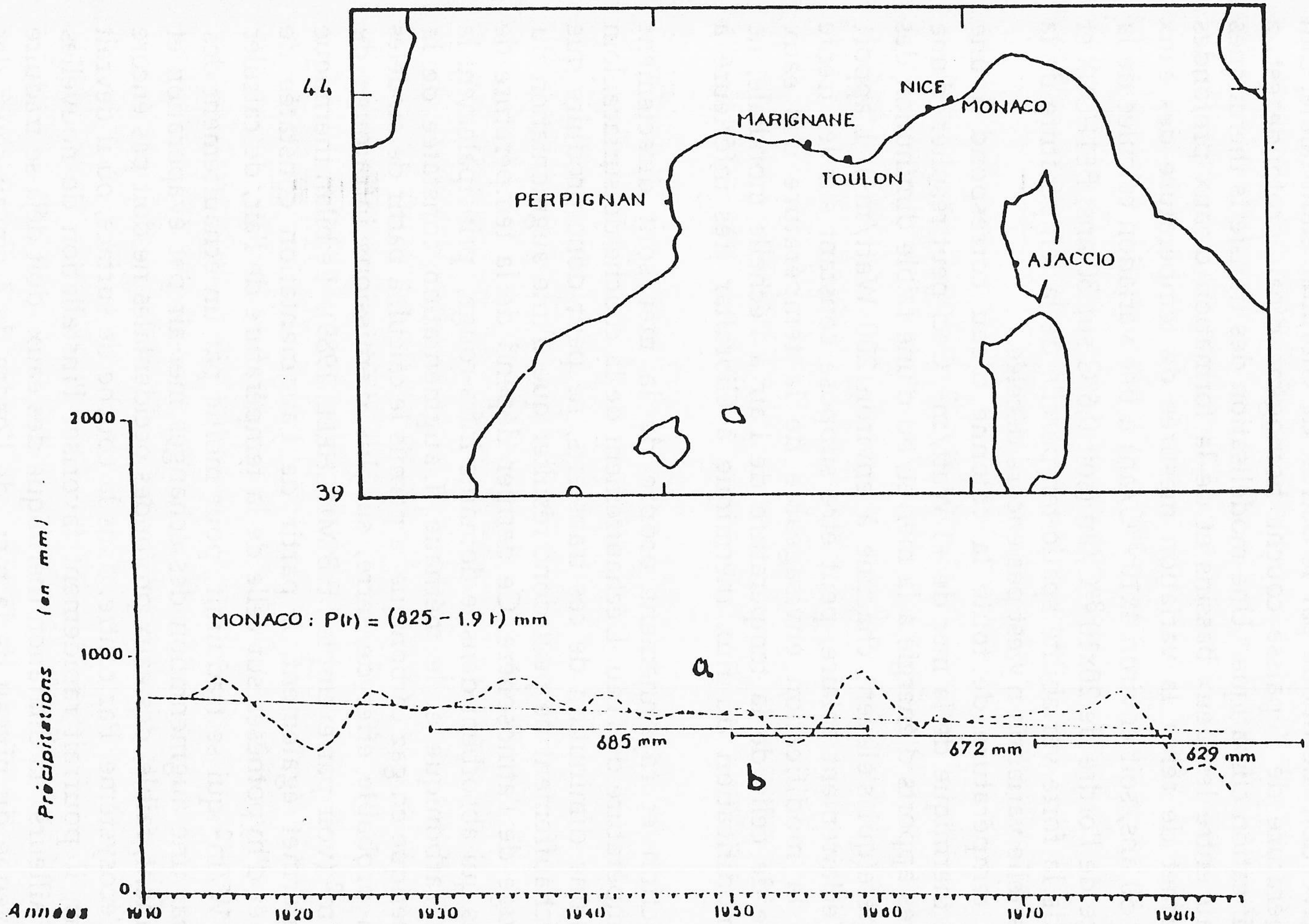

Figure 2. Evolution des précipitations à Monaco (courbe a) et dans les stations météorologiques du nord du bassin (Ajaccio, Nice, Toulon, Marignane et Perpignan, courbe b). La décroissance des précipitations depuis le début du siècle (de l'ordre de 7% sur les trente dernières années) a également été observée en Grèce et à Chypre, et en Afrique du Nord et au proche Orient. La décroissance des précipitations affecte prioritairement les ressources en eau et l'agriculture, mais également le bilan en eau de la mer, la salinité et la densité des eaux.

La variation de la salinité profonde, via la formation d'eaux denses, résulte de l'augmentation du déficit en eau à travers la surface, liée pour partie seulement à celle de l'évaporation et, par conséquence, pour partie à une diminution des précipitations. En dépit de la grande variabilité spatio-temporelle des précipitations, l'analyse des hauteurs de pluie recueillie aux stations météorologiques françaises d'Ajaccio, Nice, Toulon, Marignane et Perpignan entre 1931 et 1990 (GARNIER, 1967; Direction de la Météorologie, 1951-1970) confirme une précédente observation faite à partir des données historiques de Monaco, à savoir une diminution générale de la hauteur de pluie, de l'ordre de 7% sur les trente dernières années (CSM, 1988), Figure 2. Une diminution des précipitations a également été constatée en Grèce et à Chypre depuis les années 50 (AMANATIDIS et *al.*, 1992) et, d'après BRADLEY et *al.*(1987), les précipitations décroissent sur l'Afrique du Nord et le Moyen-Orient depuis le début du siècle, comme sur la zone 5°N-35°N. En conséquence, les précipitations en Méditerranée pourraient suivre l'évolution de celles de la zone tropicale et constituer une première réponse à la question posée de la rétro-action de l'effet de serre sur les précipitations, à nos latitudes.

1.2 -<u>hypothèse d'une conséquence de sur-consommation des apports d'eau douce</u>

Un calcul équivalent à celui fait pour la température permet, à partir du modèle de circulation des eaux, de déterminer les variations de salinité, dans l'eau intermédiaire et dans l'eau de surface du bassin Oriental, nécessaires pour expliquer l'évolution de la salinité des eaux profondes du bassin Occidental (BETHOUX et GENTILI, 1993). Le résultat du calcul est une variation de salinité de la couche de surface de $14 x 10^{-3}$ psu/an, ce qui donnerait, sur les trente dernières années, une augmentation de la salinité de surface de 0,4 psu, accompagnée d'une augmentation de température de 1,5°C, qui n'ont pas été constatées. De plus, dans une couche de surface de l'ordre de 60m d'épaisseur, la variation de bilan en eau nécessaire à une telle augmentation de salinité serait égale à $-22 x 10^{-3}$ m/an, ce qui sur 30 ans correspondrait à une diminution de 0,66m, soit à l'annulation des apports d'eau douce sur le bassin Oriental.

Selon WADIE (1984), l'apport moyen du Nil depuis le début du siècle était de $6{,}2 x 10^{10} m^3$/an, et, après la fermeture du barrage d'Assouan le débit depuis 1969 n'est plus que de $0{,}4 x 10^{10} m^3$/an. Sur l'ensemble du bassin Oriental, l'apport annuel du Nil est donc passé d'une couche d'eau de l'ordre de 4 cm à une couche de près de 2 mm. La variation attendue de salinité liée à la modification du débit du Nil ne peut être que de 0,06 psu et ne sera totalement observée que dans plus d'un siècle, compte tenu du temps de résidence des eaux du bassin Oriental. De même, la modification du bilan en eau de la mer Noire (de l'ordre de 15% actuellement), prendra au minimum un siècle avant d'affecter, sensiblement comme le Nil, la salinité du bassin Oriental, puis celle du bassin Occidental.

Malgré les imprécisions sur ces calculs qui résultent des méconnaissances des flux aux détroits et des volumes des formations d'eaux profondes, il apparaît que les modifications de température et salinité observées dans les eaux profondes du bassin Occidental ne peuvent être reliées aux seules modifications anthropiques du bilan en eau du bassin Oriental. Elles sont par contre compatibles avec l'hypothèse d'une modification des bilans en chaleur et en eau affectant simultanément les deux bassins, et probablement liées à l'augmentation de l'effet de serre.

2. Evolutions géochimiques

Elles concernent les éléments nutritifs, phosphore et azote, et les éléments métalliques traces, tels le plomb, le cadmium, le zinc et le cuivre.

2.1 - Le cycle des éléments nutritifs, phosphore, azote

Le cycle méditerranéen du phosphore fait intervenir les apports superficiels atlantiques, les rejets atmosphériques et telluriques, les transferts verticaux par activité biologique et par dynamique marine et le flux profond sortant vers l'Atlantique. Par suite de méconnaissances plus ou moins grandes sur ces différents termes, de grandes différences apparaissent entre des bilans précédemment présentés. Ainsi dans les bilans de McGILL (1969) ou de SARMIENTO et *al.* (1988), le déficit en eau de la Méditerranée est sous-estimé et les flux résultant sont 2,5 fois plus faibles que ceux proposés par BETHOUX (1980). Dans l'eau de surface Atlantique entrant en Méditerranée, SARMIENTO et *al.* (1988) et COSTE et *al.* (1988) supposent des concentrations fortes, apparemment trop fortes pour des eaux superficielles généralement considérées comme pauvres en éléments nutritifs. Entre ces estimations et celles de BETHOUX (1981) concernant la concentration des eaux de surface, il existe un facteur 7. En conséquence, d'après COSTE et *al.* (1988) l'apport principal en phosphore à la Méditerranée se fait par les eaux atlantiques entrantes, les apports telluriques ne représentant que de l'ordre de 10% des apports. Inversement, d'après BETHOUX (1981), les apports telluriques représentent 80% des apports totaux.

Une synthèse des données en phosphate des eaux profondes du bassin Occidental (BETHOUX, 1989) a également montré une augmentation des concentrations depuis les années 1960 (Figure1,courbe b). Les résultats de la campagne MEDATLANTE (P. MORIN et *al.* 1990, BETHOUX et al, 1992) confirment l'augmentation des phosphates dans l'eau profonde, observation qui constitue une contrainte du système méditerranéen. Les apports atlantiques étant supposés constants, cette évolution résulte d'une augmentation des apports telluriques liée à l'accroissement des activités industrielles, agricoles et urbaines autour de la Méditerranée. Une modélisation du cycle du phosphore en Méditerranée basée sur le schéma connu de circulation des eaux (BETHOUX, 1980) permet alors de lever le doute sur l'importance relative des apports atlantiques et telluriques et de calculer l'évolution des apports externes pouvant expliquer l'évolution des concentrations profondes. Quelque soit l'hypothèse initiale concernant l'importance relative des apports atlantiques et telluriques dans les années 60, l'augmentation de concentration des eaux profondes prouve qu'actuellement les apports telluriques en Méditerranée constituent la principale source de phosphore et leur rythme minimal d'augmentation est de 3% par an, ce qui correspond à un doublement des apports en 25 ans.

Le rapport molaire d'azote sur phosphore N/P restant constant dans les eaux profondes de la Méditerranée (de l'ordre de 23, ce qui constitue une anomalie par rapport aux grands océans où ce rapport est de 15), les apports en azote subissent la même progression que ceux en phosphore. De tels rythmes d'augmentation peuvent être comparés aux résultats d'enquêtes de l'UNEP(1988) donnant sur la période 1960-1983 des augmentations annuelles de 1,6% des habitants riverains de la Méditerranée, de 4,7% du produit national brut et de 6% de la consommation d'énergie. On vérifie ainsi en Méditerranée le scénario mondial proposé par Meybeck (1982) où les rejets telluriques en phosphore et azote dissous augmentent avec la population et avec la consommation d'énergie. Le rythme calculé d'augmentation des apports en Méditerranée peut également être comparé aux augmentations des consommations d'azote et de phosphore aux Etats Unis, de l'ordre de 5% par an depuis le milieu du dix neuvième siècle. Loin de constituer une anomalie, l'augmentation de concentration des éléments nutritifs phosphore et azote parait logique avec l'évolution de l'environnement méditerranéen et prouve que cette mer peut constituer une zone test d'étude des liaisons entre écosystème marin et environnement continental.

L' impact écologique pour la Méditerranée est certain, il est localement évident par l'occurence de plus en plus fréquente de marées rouges (eutrophisation en mer Adriatique et dans le golfe du Lion) ou plus diffus sur la productivité de la Méditerranée qui probablement doit augmenter. L'augmentation de la quantité de phytoplancton doit également favoriser, au bout de la chaîne trophique, la pêche de poissons. Cependant, dans le cycle marin du carbone, la majeure partie de la matière organique créée en surface sédimente ultérieurement en profondeur où elle subit une réaction chimique de dégradation et de reminéralisation qui entraîne une consommation d'oxygène.
Le stock d'oxygène des eaux profondes est limité par la quantité d'oxygène dissous que les eaux de surface emportent avec elles lors de la formation hivernale d'eaux profondes. Dans l'hypothèse d'une croissance continue des apports en nutritifs et de la photosynthèse, une déficience en oxygène des eaux profondes pourrait intervenir dans les 30 à 50 prochaines années (BETHOUX, 1989). Dans ce cas, la faune benthique pourrait disparaître et être remplacée par des micro-organismes anaérobies, c'est-à-dire pouvant vivre en absence d'oxygène. De tels épisodes d'anoxie perdurant quelques milliers d'années se sont déjà produits 11 fois au cours des 500.000 dernières années de l'histoire de la Méditerranée. Ils étaient alors liés à des changements climatiques et notamment à des périodes d'augmentation des précipitations (BETHOUX, 1993).

L'apport tellurique de phosphate, qui résulte du lessivage des sols (fertilisant agricole) ou des rejets industriels et urbains, est véhiculé par les cours d'eaux. Son impact sur la fertilité de la mer est évident sur les images satellitaires de la couleur de la mer, par exemple sur l'image composite de la Nasa faite à partir de 30 scènes acquises en mai 1980, qui montre trois zones de forte productivité: en mer Egée au débouché des eaux de la mer Noire, en Adriatique dans la zone d'influence des eaux du Pô et dans le golfe du Lion et en mer Catalane, avec les influences du Rhône et de l'Ebre.

Est-il possible de prévoir l'impact marin des apports telluriques en éléments nutritifs à partir de la surveillance des concentrations dans les cours d'eaux? Une synthèse d'études géochimiques concernant le Pô (MARCHETTI et *al.*; 1988) a permis de montrer qu'entre 1968 et 1984 les concentrations en nitrate avaient doublé et que les phosphates avaient été multipliés par 2,4 (ceci correspond à des augmentations respectives de 4 et 6%/an). Sur cette période les mesures régulières dans le Pô ont donc constitué un bon indicateur d'évolution des rejets anthropiques et une première réponse à l'augmentation des phénomènes d'eutrophisation en mer Adriatique. Par contre l'examen des données du Rhône (Anonyme, 1987) montrent une concentration en phosphate plus ou moins constante sur la période 1971-1988 et sur les 200 derniers kilomètres avant l'estuaire. On ne peut malheureusement pas en déduire une stabilité des rejets, mais plutôt une saturation du fleuve en éléments chimiques dissous. D'après GOLTERMAN (1985), la concentration en phosphate dépend non seulement des rejets, mais encore de la concentration en calcium, du pH et de la température. Dans le cas du Rhône, l'augmentation probable des rejets au cours des dernières décennies doit se traduire par l'augmentation du phosphore absorbé sur les particules et passe donc inaperçue dans les mesures de phosphate dissous.

Plus généralement, les mesures d'éléments dissous mises en oeuvre pour étudier l'environnement fluviatile et les rejets telluriques à la mer ne sont plus suffisantes dans la mesure où l'apport maximal passe dans le transit particulaire, difficile à appréhender et particulièrement méconnu. Les études de bilan du phosphore en Méditerranée (BETHOUX et *al.*, 1992) et les études de comportement des différentes formes du phosphore dans les estuaires (FROELICH, 1988) confirment que l'apport principal de phosphate à la Méditerranée provient de la faible partie du phosphore particulaire qui se dissous dans les estuaires. Tant pour le transfert du phosphate que pour différents éléments métalliques traces, les estuaires constituent des zones soit d'enfouissement, soit de dissolution qui conditionnent les transferts au milieu marin. En ce qui concerne le cycle marin de l'azote, les bilans en Méditerranée montrent qu'une part principale des apports doit provenir de la captation biologique d'azote moléculaire (atmosphérique) par des organismes spécilisés soit planctoniques (Trichodesmium, Synechococcus...) soit vivant en symbiose avec les "algues" posidonia oceanica. Ce fonctionnement spécifique de l'écosystème méditerranéen peut expliquer le rapport anormal N/P mesuré dans les eaux profondes et peut résulter, a priori, du caractère continental de cette mer, favorisant les apports telluriques en phosphore. L'apparente constance du rapport N/P malgré l'augmentation récente des apports anthropiques en phosphore semble prouver la parfaite adaptation de l'écosystème.

2.2 - <u>les éléments métalliques traces</u>

L'utilisation des éléments métalliques présents à l'état de trace dans l'eau de mer (concentrations comprises entre 10^{-9} et 10^{-12} mol/kg) comme traceurs de pollutions et de circulation de masses d'eaux est délicate car elle nécessite la maîtrise de méthodes analytiques et de différents problèmes de contamination pouvant intervenir tant lors du prélèvement que lors du transfert de l'échantillon et de son analyse. Des mesures fiables de concentration en métaux traces n'existent pratiquement que depuis les années 1981-83 (campagnes géochimiques PHYCEMED). Il n'est donc pas possible de déceler directement une évolution qui aurait accompagné celles des activités anthropiques autour de la Méditerranée sur la période 1960-1985. Les bilans à grandes échelles sont encore plus difficiles que pour les nutritifs car, outre la fiabilité des mesures, ils font intervenir le cycle propre de chaque élément métallique, son affinité biologique et ses taux de sédimentation et de remobilisation. De plus, les mesures faites de part et d'autre du détroit de Gibraltar montrent quelquefois des concentrations anormalement fortes dans l'eau atlantique entrante (par exemple, BOYLE et *al.*, 1985, SHERREL et BOYLE, 1988; VanGeen et *al.*, 1988) qui résultent probablement de la zone de rejets de boues industrielles dans le golfe de Cadix (RUIZ-PINO et *al.*, 1993). Dans ce cas les eaux atlantiques entrantes peuvent paraître plus riches en certains métaux que les eaux méditerranéennes et un bilan dans l'hypothèse d'un état stationnaire conduirait alors à nier l'existence de rejets atmosphériques et telluriques en Méditerranée. D'où l'importance de la notion d'état non stationnaire développée dans les années 90 pour expliquer les données obtenues et la géochimie méditerranéenne.

Alors que les profils verticaux d'éléments métalliques traces dans les océans ressemblent à ceux des nutritifs, à savoir de faibles concentrations en surface et une augmentation régulière avec la profondeur, en Méditerranée les profils sont plus ou moins uniformes de la surface au fond, avec de relatives fortes valeurs en surface. On peut expliquer ces profils par l'hypothèse d'un état non-stationnaire, les fortes valeurs superficielles résultant d'apports anthropiques récents (de l'année) alors que les valeurs plus ou moins constantes de la couche profonde sont les vestiges d'un pseudo

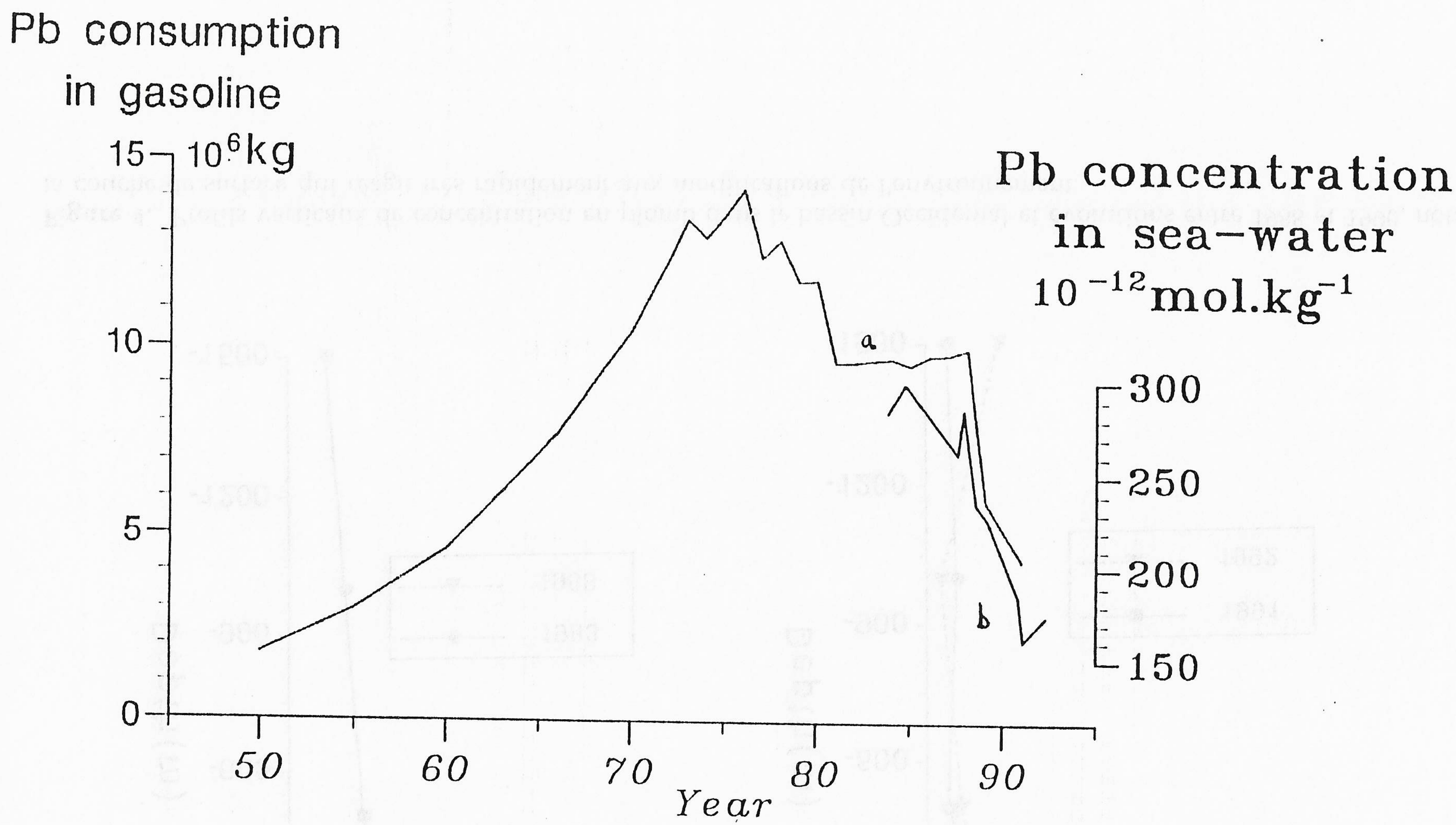

Figure 3, courbe a: Evolution de la consommation du plomb dans les essences en France. De1950 à 1976, l'augmentation de 9 à 10% par an reflète les années de fortes expansions économiques. L'accident de 1973-74 concerne le premier choc pétrolier, la décroissance entre 1976 et 1981 est liée à la première réglementation à la baisse des additifs plombés, de 0,64 à 0,4 g/l. La forte décroissance depuis 1988 résulte de la deuxième diminution des additifs de 0,4 à 0,15 g/l en 1991, ainsi que de l'importance croissante de l'usage de l'essence sans plomb et du gazole.

La courbe b donne l'évolution de la concentration moyenne en plomb de la couche 0-100m dans le nord du bassin Occidental; la diminution de concentration entre 1988 et 1990 est évidemment liée à celle des apports atmosphériques en plomb anthropique.

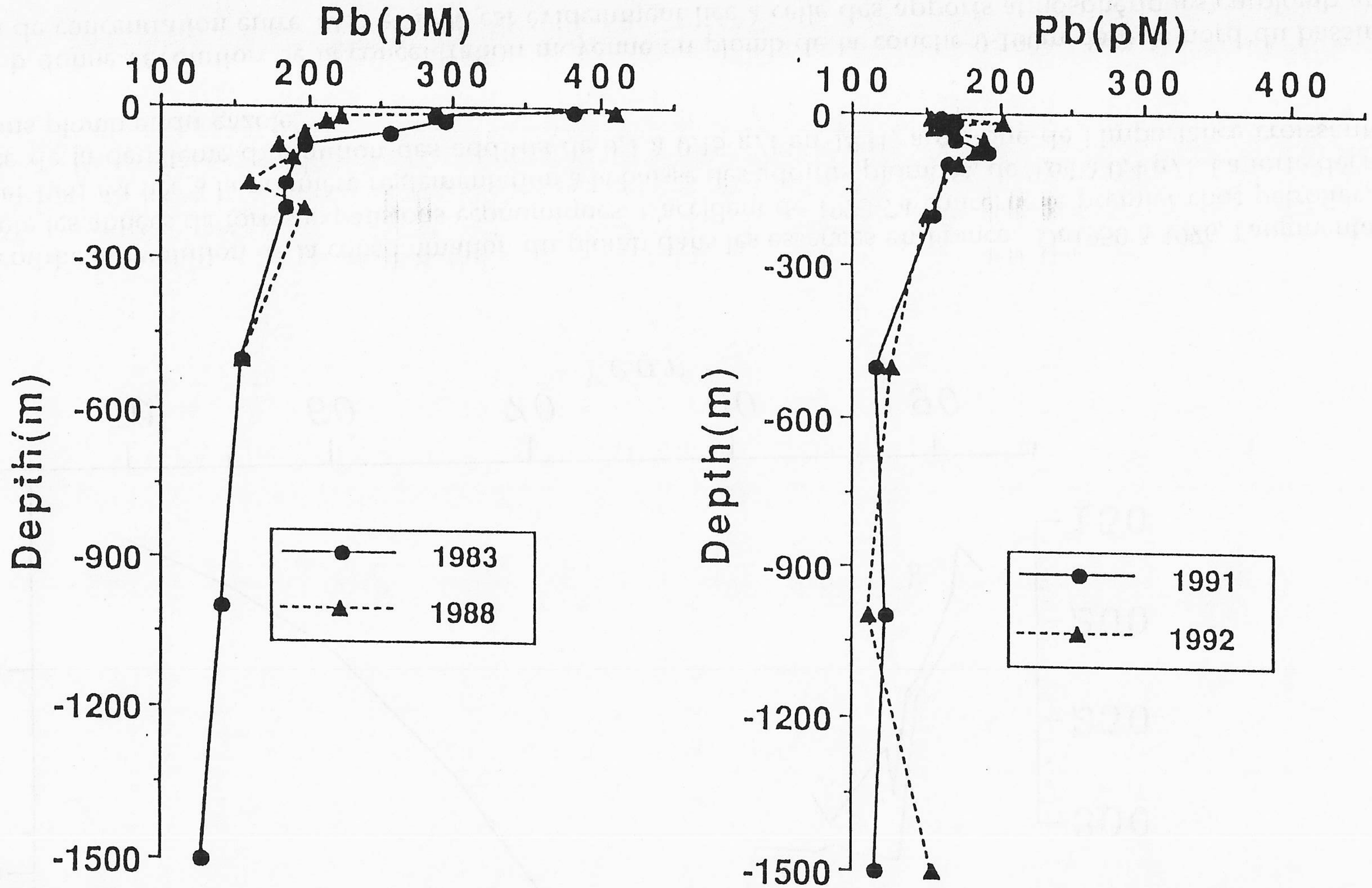

Figure 4. Profils verticaux de concentration en plomb dans le bassin Occidental et évolutions entre 1988 et 1990, notamment dans la couche de surface qui réagit très rapidement aux modifications de l'environnement.

équilibre des années 1950-60, antérieur à la forte progression des activités autour de la Méditerranée depuis les années 60 (RUIZ-PINO et *al.*, 1990; 1991; BETHOUX et *al.*, 1990b).

Là encore, il est possible, à partir des concentrations marines, d'estimer une progression des apports anthropiques à la Méditerranée de 6% par an pour le zinc et le plomb, et de 2% par an pour le cadmium et le cuivre entre 1960 et 1983. Ceci reflète les rôles majeurs du zinc dans les activités humaines et du plomb utilisé comme antidétonnant dans les essences (BETHOUX et *al.*, 1990 b). Il est à noter qu'il n'existe encore qu'une évaluation globale des apports telluriques à la Méditerranée, réalisée à partir des enquêtes du Programme des Nations Unies pour l'Environnement au cours des années 70 (UNEP, 1984), et qu'il n'y a pas de données concernant l'évolution des rejets dans le temps. Par contre, les données socio-économiques (UNEP,1988) montrent que sur la période 1960-1983, parallèlement à l'augmentation du nombre de riverains de la Méditerranée et de leur niveau de vie, la consommation d'énergie a augmenté de 6% et le nombre de voitures de 7,5% par an. Ce sont les conséquences de cette évolution socio-économique que l'on constate dès maintenant dans la géochimie des eaux profondes.

Le plomb, dont les émissions anthropiques liées à la consommation de carburant ont fortement supplanté les apports naturels, constitue un traceur particulièrement intéressant dans la mesure où son injection atmosphérique a évolué au cours des quarante dernières années. La figure 3, courbe a, donne la consommation du plomb en France dans les essences (Paul Tepik, UFIP, communication personnelle). On peut remarquer de 1950 à 1976 l'augmentation constante de 9 à 10% par an liée à l'expansion économique, l'effet en 1973-74 du premier choc pétrolier, la décroissance entre 1976 et 1981, consécutive à la première diminution des additifs de 0,64 à 0,4 g/litre et depuis 1988 la forte décroissance liée à la deuxième diminution des concentrations de 0,4 à 0,15 g/l en 1991, décidée par la réglementation européenne, et à l'augmentation de la consommation d'essence sans plomb et de gazole. Une première conséquence de la diminution des émissions de plomb concerne la décroissance du plomb mesuré dans les aérosols et les pluies à Monaco et au Cap Ferrat entre 1987 et 1990 (MARMANTEAU, VEGLIA, 1992; MIGON et *al.*, 1993). Une deuxième conséquence est la nette diminution du plomb dissous dans la couche de surface en mer Ligure entre 1988 et 1992 (Fig.3, courbe b, Fig. 4; NICOLAS, 1993, communication personnelle). Ces résultats confirment :

-l'importance des apports atmosphériques d'origine anthropique dans le cycle du plomb en Méditerranée,

- l'équilibre de la couche de surface avec les apports instantanés et le bien fondé de la politique de diminution des rejets puisque dans l'espace de un à deux ans la concentration marine du plomb a diminué dans la couche de surface.

3. Conclusion

De par sa dynamique propre, ses interactions avec l'atmosphère et la pression de 130 millions d'habitants et 150 millions de touristes sur son pourtour et ses îles, la Méditerranée constitue une zone test pour les études des modifications du climat et de l'environnement. La nécessité de telles études a motivé la création du Programme International Géosphère Biosphère (PIGB) qui vise à décrire, comprendre et modéliser l'ensemble des processus physiques, chimiques et biologiques qui régulent les conditions environnementales sur la Terre.

Dans le bassin Occidental, il est possible de déceler des évolutions sensibles des caractéristiques physiques et chimiques des eaux profondes qui sont la preuve qualitative d'une évolution du climat et de l'environnement en Méditerranée. Elles sont également la preuve d'une évolution plus forte des eaux superficielles même si elle est encore masquée par la grande variabilité spatio-temporelle de la couche de surface. Ces changements dans l'eau profonde ont été decelés, presque par hasard, de l'analyse de mesures effectuées au cours des trente dernières années lors de campagnes océanographiques à thématiques dynamiques ou géochimiques destinées à décrire le système " méditerranée". Maintenant, compte tenu des résultats exposés, doit être organisée une surveillance de l'évolution des eaux en liaison avec celles du climat et de l'environnement. Pour accéder aux couches profondes et aux zones hauturières, cette surveillance nécessite des moyens importants mais classiquement mis en oeuvre lors des campagnes océanographiques. Les programmes de sciences et technologies marines de la CEE (MAST), et plus particulièrement le projet intégré Méditerranée (MTP) devraient prochainement initialiser cette surveillance.

L'exploitation quantitative du signal marin pour déterminer l'évolution des forces extérieures (le climat et l'environnement) nécessite une modélisation via la dynamique marine et l'activité biologique (cette dernière influant le transfert vertical des éléments chimiques). Les calculs présentés dépendent des flux d'eaux aux détroits et/ou des flux de formation d'eaux profondes, tous mal connus (variation d'un facteur 2 entre les estimations des flux au détroit de Gibraltar, d'un facteur 4 pour les flux de formation d'eaux profondes). Ils dépendent également des rôles respectifs des eaux profondes de la mer Tyrrhénienne et de la mer Ionienne et des évolutions qui pourraient y être decelées. Des études de modélisation de la circulation et des flux de formation d'eaux profondes sont en cours dans les deux grands bassins, par exemple dans les groupes EUROMODEL et MERMAIDS qui relèvent de MAST. Elles doivent être poursuivies jusqu'à l'obtention des différents flux et de leurs variabilités saisonnières et interannuelles.

Les données marines permettent une estimation de changements survenus à la surface de la Méditerranée, à l'échelle spatiale de cette mer et à l'échelle de temps de l'année et de la décennie. Compte tenu de la variabilité spatio-temporelle des caractéristiques atmosphériques, la vérification de l'hypothèse d'un changement climatique nécessite une synthèse des données obtenues dans un grand nombre de stations météorologiques tant dans le bassin méditerranéen que dans l'hémisphère nord.

La variation de concentration en phosphate permet d'estimer une augmentation des apports telluriques, logique avec d'autres données socio-économiques d'évolution du nombre d'habitants et de leur niveau de vie. Mais elle ne peut être vérifiée quantitativement, les enquêtes de l'UNEP (1984) ne donnant qu'une évaluation globale des apports sur la décennie 1970 et ne pouvant traiter d'évolution temporelle. De même, les bilans marins de nutritifs posent le devenir des apports particulaires, du bilan des apports des rivières et de la méthodologie à employer pour caractériser et suivre l'évolution des rejets anthropiques, malgré la variabilité spatio-temporelle des rejets et des vecteurs de transport. Il en est de même de l'évolution des concentrations en éléments métalliques traces qu'il est impossible de relier quantitativement aux transports atmosphériques et telluriques, à nouveau très variables spatio-temporellement autour de la Méditerranée.

Aux grandes échelles de temps et d'espace, la Méditerranée constitue donc un observatoire idéal ne nécessitant qu'un nombre limité de mesures marines de qualité.

Elle oblige cependant à redéfinir le cadre et la finalité des prélèvements atmosphériques et des contrôles fluviatiles et terrestres, généralement menés à petites échelles de temps et d'espace, afin de les harmoniser avec les recherches marines, dans une thématique globale.

A plus petites échelles de temps et d'espace, particulièrement dans les zones côtières, la variabilité spatio-temporelle des rejets et de la dilution nécessitent des mesures nombreuses. Indépendamment de problèmes immédiats de salubrité et de toxicité qui relèvent de MEDPOL/PAM/UNEP, une évolution du milieu, liée à des causes plus diffuses, par exemple les apports atmosphériques ou l'évolution du climat, ne pourra être décelée que par de longues séries temporelles, par l'analyse de multiples paramètre et par la prise en compte de multiples signatures chimiques et indicateurs biologiques (notamment bio-diversité, eutrophisation, apparition de nouvelles espèces...).

Transport et diffusion des contaminants

par Claude MILLOT

Antenne COM, IFREMER, B.P. 330, 83507 - La Seyne-sur-Mer, France

Dans la zone côtière, la circulation des eaux qui conditionne le transport et la diffusion des polluants d'origine terrestre dépend de phénomènes locaux, voire régionaux, tout en étant forcée par la circulation à une échelle dite générale, dont les caratéristiques ont été présentées dans le Chapître d'Introduction.

1. Les phénomènes locaux

Le vent est cependant le principal phénomène conditionnant localement la circulation des eaux côtières. En fonction de l'orientation qu'il a par rapport à la côte, de la courbure de cette côte et de la stratification, le vent, plus ou moins, accumule à la côte ou éloigne vers le large les eaux de surface; par continuité, celles-ci chassent ou sont remplacées par des eaux plus profondes. Pour des vents forts, ces mouvements dans un plan vertical peuvent ainsi ramener vers les petits fonds des produits qui sont déversés à plusieurs centaines de mètres de profondeur. Ils sont associés à des mouvements horizontaux d'échelle locale, voire régionale: dans le Golfe du Lion, par exemple, les vents de nord-ouest induisent des circulation fermées de plusieurs dizaines de kilomètres dans la couche de surface, et une circulation le long des isobathes opposée à la circulation générale dans la couche profonde (Millot, 1990). Dans une telle situation, des produits dissous pourraient parfaitement revenir après plusieurs jours dans la zone où ils auraient été déversés.

Lorsque les conditions météorologiques sont relativement clémentes, le phénomène de brise thermique, bien que plutôt favorable à la dispersion de polluants superficiels, à tendance à les entraîner vers la côte (le large) dans la journée (la nuit). La brise de mer (terre) étant généralement plus intense en été (hiver), ce phénomène est relativement défavorable en été dans les régions touristiques, même si les rejets urbains, alors importants, sont faits à plusieurs kilomètre du rivage.

Les vents forts favorisent la dilution des polluants en agitant les couches superficielles par l'intermédiaire des vagues et de la houle. Celles-ci, étant associées à des mouvements orbitaux qui peuvent être relativement intenses jusqu'à plusieurs dizaines de mètres de profondeur, sont le principal facteur entraînant la formation de la couche mélangée de surface. En zone côtière ainsi que, dans des conditions extrêmes, sur l'ensemble du plateau, elles peuvent remettre en suspension les sédiments les plus fins et favoriser alors la dispersion de polluants piégés qui pourront ensuite être advectés par la circulation. Les zones sédimentaires les plus polluées, situées à l'embouchure des fleuves qui drainent les pays du nord, ne sont que peu souvent concernées par de fortes houles, celles-ci n'étant créées qu'avec un fetch de plusieurs centaines de kilomètres.

La rotation de la terre fait que tous les rejets importants et peu denses (rivières, gros émissaires), au même titre que la circulation générale des différentes masses d'eau, s'écoulent le long des côtes situées à leur droite; c'est par exemple le cas des eaux du Danube en Mer Noire. Ces rejets superficiels sont très fortement soumis à l'action du vent: certains sont la plupart du temps plaqués contre la côte sur plusieurs centaines de kilomètres, comme le Pô par la Bora le long de la botte italienne et l'Ebre par les vents de nord-nord-est dans le Golfe de Valence, tandis que d'autres sont souvent dispersés, comme le Rhône par le Mistral dans le Golfe du Lion et les eaux de la Mer Noire par le Meltem et les vents de nord dans le nord de la Mer Egée (Le Vourch et al., 1992). Soulignons que le débit de chacun des grands fleuves (généralement inférieur au millier de m^3/s) n'est que de l'ordre du millième du débit de la circulation générale qui s'écoule au large de leur embouchure.

Enfin, on doit noter que le marnage relativement faible (quelques dizaines de centimètres avec des contributions équivalentes de la marée, du vent et de la pression atmosphérique) que l'on rencontre le long de la plupart des côtes méditerranéennes, sauf dans des endroits particuliers tels que le fond de l'Adriatique ou le Golfe de Gabès à cause de l'amplification de certaines ondes de marée, n'est pas favorable au nettoyage du littoral et des étangs côtiers.

2. L'apport potentiel de la modélisation

Il faut tout d'abord souligner que la modélisation analytique ou numérique en termes d'études de processus est la seule pouvant permettre une bonne compréhension des phénomènes décrits par l'observation du milieu. Ce n'est qu'après cette étape indispensable que l'on peut envisager, au moyen de modèles numériques prenant en compte le plus grand nombre possible de paramètres, une modélisation qui sera validée par les similitudes plus ou moins grandes qu'elle aura avec les observations.

Dans cette optique, on doit avoir conscience que notre compréhension des moteurs de la circulation en zone côtière est très différente selon que l'on considère les phénomènes locaux ou la circulation générale. Si les premiers, pour la plupart, découlent d'équations relativement simples, aucun des modèles de circulation générale élaborés à ce jour n'a permis, par exemple, de préciser les raisons pour lesquelles on observe une circulation relativement stable et puissante le long de la pente continentale au nord des bassins. Certains modèles privilégient la formation hivernale d'eau dense, d'autres les échanges thermohalins avec l'atmosphère, d'autres le forçage par les apports côtiers d'eau douce, d'autres enfin la tension des vents dominants; ces mécanismes interviennent probablement tous, mais à des degrés que nous sommes actuellement incapables de préciser.

De plus, si tant est que l'on puisse disposer d'un modèle de circulation générale, celui-ci devra avoir, pour des raisons évidentes de temps de calcul et donc de coût, des pas d'espace (plusieurs kilomètres) et de temps (plusieurs dizaines de minutes) relativement grands. Afin de pouvoir utiliser un tel modèle pour l'étude de la circulation en zone côtière, on peut envisager de le concevoir avec une maille spatiale variable permettant, en particulier, une représentation correcte de la topographie; c'est cependant une approche peu satisfaisante car les pas nécessaires dans le domaine côtier sont beaucoup plus petits (quelques centaines de mètres et quelques minutes). La solution la plus prometteuse est de concevoir des modèles emboîtés, les conditions aux limites du modèle côtier étant données, tous les N pas de temps ou d'espace, par le modèle général.

Ceci étant, même si certaines équipes sont sur le point d'avoir un modèle représentatif des grands traits de la circulation générale et de sa variabilité saisonnière, il ne faut pas cacher que la turbulence engendrée par cette circulation, qu'elle soit à moyenne échelle comme dans le sud des bassins ou, a fortiori, à petite échelle comme dans les zones côtières, n'est pas près d'être modélisée de manière pronostique. La conviction de l'auteur est que les courants induits par ces turbulences sont souvent beaucoup plus intenses que ceux induits par les phénomènes locaux. A court et moyen termes, le transport et la dispersion des polluants d'origine terrestre ne pourront donc être évalués que dans des cas académiques ou de manière statistique, et tout modèle côtier opérationnel devra assimiler des observations.

3. Priorités et opportunités d'intervention

D'un point de vue recherche sur le terrain, la conduite de campagnes de mesures qui ne seraient que locales, dans une baie par exemple, ne permet absolument pas de comprendre la circulation qui s'y développe. Toute étude en zone côtière doit donc empiéter sur le domaine du large: la composante de la récente expérience PRIMO-0 conduite au large de Nice a montré que la variabilité de la circulation, cohérente dans une bande côtière de plus de 10 km de large, était principalement due à la turbulence induite par la circulation générale. Comme l'a aussi confirmé cette expérience, il est nécessaire d'avoir beaucoup de mesures simultanées et corrélées: il faut encourager la création d'un nombre limité de zones-atelier où toutes les équipes devraient mettre leur équipement en commun. Ces actions peuvent être controlées par le Parlement Européen au niveau des appels d'offres et du soutien aux projets.

D'un point de vue modélisation, il faut encourager les études théoriques sur les techniques d'emboîtement de modèles. Il faut également souligner l'importance fondamentale des conditions aux limites imposées aux modèles côtiers, et ne pas cautionner les hypothèses simplistes supposant que la circulation à l'ouvert d'une baie a des caractéristiques (sens, intensité, structure verticale) identiques à celles de la circulation générale qui se développe à plusieurs kilomètres au large. Il faut enfin admettre qu'un modèle de circulation qui ne serait pas validé par des observations n'a pas plus d'intérêt qu'une analyse de données qui ne serait pas étayée par un modèle: compte tenu de la complexité des phénomènes qui se développent dans le domaine côtier, observateurs et modélisateurs doivent travailler en étroite synergie. Là encore, le contrôle est relativement facile, d'autant que ceux des groupes-MAST qui ont déjà adopté une telle stratégie obtiennent des résultats particulièrement encourageants.

D'un point de vue suivi de la circulation des eaux dans un domaine limité de la bande côtière, la conception d'un système de surveillance doit s'appuyer sur la collecte et la transmission en temps réel d'observations courantométriques réalisées aux limites extérieures de ce domaine. Quelques courantomètres mis en oeuvre à quelques kilomètres au large d'une rade, ainsi que des observations météorologiques locales, pourraient être assimilées efficacement dans un modèle performant de circulation. Lorsqu'un tel modèle existera, le financement d'une expérience pilote, qui pourrait même être conduite en temps réel, ne posera pas de problèmes techniques et financiers majeurs.

Si la formation de compétences en modélisation ne requiert pas de besoins particuliers, ne peut avoir de conséquences pécuniaires graves, et n'a pas d'incidences sur la sécurité des personnes, il en va tout autrement pour ce qui concerne l'obtention de mesures in situ. La mer est d'abord un milieu relativement hostile (problèmes liés à l'agitation superficielle, à la corrosion, à la couverture végétale, aux morsures de poissons, aux contraintes de pression, etc...) qui nécessite donc une instrumentation onéreuse facilement perdable. Les activités scientifique, militaire, de pêche et de commerce n'y cohabitent pas facilement: par exemple, la pose de mouillages est soumise à autorisation de la préfecture maritime qui y voit parfois un danger pour les sous-marins; un mouillage est également un obstacle au chalutage et, parfois, à la navigation. Enfin, les grosses opérations que l'on a pu conduire ne sont pas fréquentes et, le personnel technique qualifié étant extrêmement réduit, les scientifiques doivent faire beaucoup par eux-mêmes: le travail à la mer, par nature délicat, peut devenir dangereux pour des personnels relativement inexpérimentés. Ces grosses opérations pouvant facilement être espacées dans le temps, la solution pour qu'elles puissent bénéficier d'un personnel technique adéquat passe par la création de postes volants au niveau européen.

L'océanographe dynamicien n'a généralement que peu de relations avec les diverses collectivités locales car il n'apporte pas d'informations directement exploitables sur la nature ou la concentration de polluants. De plus, il n'est généralement capable d'indiquer qu'en termes statistiques, et non pronostiques, le devenir de telle ou telle masse d'eau; à ce titre, il est parfois consulté avant l'implantation d'un émissaire ou d'une ferme aquacole, bien que les contraintes économiques soient souvent déterminantes. En somme, il observe et tente de comprendre des phénomènes sur lesquels, à la différence de certains de ses collègues, il ne peut intervenir. Ceci étant, à la différence de ces collègues, les paramètres qui le concernent sont assez facilement mesurables et les équations qu'il doit utiliser sont rigoureuses et, comparativement, simples: il peut acquérir des séries temporelles relativement longues et faire tourner des modèles pendant relativement longtemps. Ainsi, les outils qu'il a à sa disposition lui permettent d'avoir, peut être plus que d'autres, conscience de la grande variabilité du milieu marin. Par quel mystère l'hétérogénéité des caractéristiques hydrologiques et dynamiques ne se retrouverait-elle pas dans la distribution des sels nutritifs, de la chlorophylle ou des polluants? Cette notion de la variabilité est loin d'être générale, et c'est donc toute la communauté scientifique qui devrait être incitée à rechercher ou intensifier le dialogue et la collaboration avec les océanographes dynamiciens.

Mediterranean pollution

Chemical and biological aspects

by Michael SCOULLOS

Environmental and Marine Chemistry, University of Athens, Panepistimiopolis, 10571 - Athens, Greece

INTRODUCTION

For a valid and systematic assessment of the state of pollution in the Mediterranean, an exercise started already in 1972 (GFCM - CIESM) and continued since (see AMBIO, 1977; FOWLER, 1985; UNEP, 1990; BRIAND, 1992), it is necessary to understand and follow, at least to a certain extent, the philosophy of the projects which have generated the data available to date.

The vast majority of the programmes carried out in the Mediterranean are based on analyses of a relatively short list of chemical substances in few abiotic matrices namely seawater, coastal and offshore sea-bottom sediments, to a lesser extent suspended particles and to a relatively very small number of samples of marine aerosols, seasurface films and interstitial waters. The relevant determinations in biota were focused mainly on mussels and red mullet and in a relatively small number of other organisms, plankton, algae, various benthic species, fish and very rarery in reptiles and marine mammals. The number of investigations concerning the fate and transformations of substances in the Mediteranean environment is still very small but growing fast.

The "state of pollution" in the Mediterranean, which is a very complex sea with rapidly changing socioeconomic and cultural conditions (and therefore "pressures") around it could be understood through a dynamic synthesis of a series of overlapping pictures.

Each one of them corresponds to the effects of a given source, phenomenon or basic parameter on the distribution of each pollutant in each matrix (aerosols, seawater, sediments, biota). For instance the effects of one kind of parameters (eg. of pH, temperature or salinity etc.) or of a given kind of sources (eg. sewage outfalls, ships, agricultural runoff, land traffic etc.), or of physical phenomena (eg. the typical water circulation or the atmospheric circulation or the Saharan dust episodes), or geological characteristics (eg. its seismic and volcanic activity, the Himalayan mercury belt)) or large scale anthropogenic interventions of local nature (eg. rapid increase of the dams on major waterways) or of global scale (eg. climatic changes, sea level rise, decrease or seasonal disturbance of rainfalls). Such an approach could be obtained if appropriate data bases existed.

It is known that each chemical substance or group of similar substances is produced, used and distributed and taken up by biota in different ways and it is affected to a different extend by a given physicochemical phenomenon and /or biological mechanism. Therefore its final distribution to the various matrices vary and the trends and problems connected with it might have similar or quite different interpretations.

During the Pre-Stockholm period all research in the area was initiated by independent scientists and laboratories financed mostly by national or regional authorities and presented mostly in the CIESM biannual Conferences and few international journals. Since the establishment of the MAP/UNEP and the MED POL programmes many researchers, coordinated mostly by their national coordinators, provided data through programmes supported exclusively or partly by UNEP and/or by their governments in the framework of their commitments to the MAP UNEP programme. Undoubtedly these works, despite their short comings in respect of intercallibration and intercomparisons contributed a lot in identifying "hot-spots" focusing on real questions and excluding superficial hypotheses. The limited and irregular funding, the delays in publication of reports, in some cases the State control on release of data and also the saturation of international literature with masses of partly interpreted data has gradually discouraged many scientists to invest a lot of time and energy to participate in monitoring projects.

Since the early 80's and most systematically in the last five years the EC has funded research in the Mediterranean through its STEP, MAST and other programmes (see EROS-2000, EUROMARGE etc) which have generated very high quality results. Some of them confirm older findings, others fill the most obvious gaps in our knowledge eg. on aerosols and the fate of some important substances whereas some of the new data ask for a revision of what was consider as "typical" Mediterranean level, particularly in seawaters.

Although we are at present still in a transition period as it is concerned our understanding about the contribution of the various sources and inputs one could safely state that the diffuse sources mainly from the European continent via the atmosphere play a fundamental role in the pollution of the Mediterranean Sea. Therefore the role and responsibilities of the EC are important not only in financing and facilitating research and pollution abatement in the Mediterranean region but also in reducing, through appropriate legislation and incentives, the pollution in Europe and its inputs to the Mediterranean.

In order to summarise the existing knowledge on the Mediterranean Pollution in a systematic way avoiding over simplifications we will try to examine briefly but systematically the major polluting substances in their way from their sources to the sea, their fate, concentration and distributions in seawater and sediments and their uptake by marine biota and, through seafood, by man who is subject to various degrees of risk because of them.

The major pollutants identified and examined are the following : Trace metals (mercury, cadmium, arsenic, lead, copper and zinc), organotins, halogenated hydrocarbons, organophosphorus pesticides, petroleum hydrocarbons, radioactive substances, litter, microbial pollution allocating more space for those studied best because of their importance for the area.

TRACE METALS

Trace metals potentially harmful to the marine environment and through seafood to man have been studied for years in the Mediterranean. Priority was given during the planning of MED POL phase I to mercury and cadmium, since preliminary surveys had shown that both occur in the marine biota in high concentrations. Levels of both have been extensively reviewed in documents of UNEP/FAO/WHO, 1987; 1987a; 1990; BERNHARD,1988. A new document in this series under publication (SCOULLOS 1993, in press) reviews the situation for zinc and copper.

In this point one should recognise that in most cases published and/or reported results are based on simple statistics which might prove to be misleading since it is well known that actual concentrations of trace metals in the water column are often quite different from "average values". This is why some single values published by groups participating in intercallibrations and using "state of the art" methodologies are given in several cases in the present overview more weight than masses of data produced with questionable accuracy and prudence.

Recent individual investigations have confirmed elevated levels of heavy metals which are potentially toxic to man, found in edible biota. For example, SCHUHMACHER *et al*, (1990) have shown that elevated levels of lead and cadmium in a number of marine species commonly consumed by man along the Tarragona coastal area (Catalonia, NE Spain), may constitute a potential health hazard. This region, with an important commercial fishing industry received inputs from two rivers, the Ebro (South) and the Francoli, polluted by toxic industrial residues (including heavy metals). AUGIER *et al* (1989) have shown that the edible sea urchin *Paracentrotus lividus* (Lamarck) collected in four selected areas of the seashore of Marseille carried high body burdens of cadmium, copper, lead and mercury in consumable parts such as milts and guts.

Mercury

Mercury in the Mediterranean has been reviewed by BERNHARD and RENZON (1977), FOWLER (1985), BERNHARD (1985) and UNEP (1989).

Sources, Transport:

The Mediterranean belongs to the Himalayan - Mediterranean mercury belt. The observed high levels of mercury in the area and particularly in its biota are attributed, at least partly, to this geochemical anomaly. It is noteworthy that approximately 65% of the world's Hg mineral resources are located in the region.

The anthropogenic mercury is found mainly in the metallic form in wastes from industrial plants (chloro-alkali and PVC production) where it is used as a catalyst or in one of its many applications in electric industry (lamps, thermometers etc). Due to its high volatility its main pathway to the marine environment is via the atmosphere, from which it is scavenged by rain and to a lesser extent as dry deposition. Although its natural emissions, (earth mantle degassing), are more important than the anthropogenic ones, at the local scale, the latter are often of greater significance and consequences (MILLER and BUCHANAN, 1979).

Distribution, Concentrations:

Atmosphere:

The number of mercury determinations in the Mediterranean air are limited and come mostly from Tuscany and the Ligurian coast. (BREDER *et al*, 1983; BREDER and FLUCHT, 1984; FERRARA *et al*, 1984; ARNOLD *et al*, 1983). The data show that Hg levels over the sea are lower than over the land and particularly over urban areas. The levels over Sicily (0.1 ng Hg $/m^3$) and the Western Mediterranean (0.24 ng Hg $/m^3$) are clearly higher than those over the North Atlantic (0.065 ng Hg $/m^3$). Similarly the deposition over the W. Mediterranean is assessed to 50µg Hg-T $/m^2$ /yr (BUAT-MENARD and ARNOLD, 1978; ARNOLD, 1983) compared to a global deposition of 4-30 µg Hg-T $/m^2$ /yr (LINDQVIST *et al*, 1984).

Seawater:

Mercury concentrations in Mediterranean seawater vary over a wide range depending on the proximity to a source but also on the use of different methods without proper intercomparisons or intercalibrations. This makes comparison of the data difficult, if not impossible (UNEP, 1989).

Very recently COSSA and MARTIN (1990) reported very low dissolved mercury concentrations in the deep waters of the Gulf of Lions, with values ranging from 0.16 to 1 ng /l, 2 orders of magnitude lower than the previous estimates. These values are comparable only to those of the southern Adriatic (0.4 ng /l) as reported by MIKAC *et al* (1989) and to those of the Alboran Sea (0.28 ng/l) (COURAU pers. communication, in COSSA and MARTIN, 1990) and they are very similar to those of the Atlantic and the Pacific waters. The aforementioned authors carried out measurements of dissolved and particulate mercury in the Rhone delta and found even there relatively low dissolved Hg concentrations (1.6 - 3.6 ng /l), which are in agreement with values of other French rivers (DORTEN *et al*, 1990; COSSA *et al*, 1990), but still elevated when compared with the pristine Krka river, Croatia (0.3 - 0.4 ng /l) (MIKAC *et al*, 1989). The particulate mercury values were found to be elevated (1.1 µg /g) especially when compared with fresh water seston of remote areas (0.1 - 0.5 µg /g). The authors conclude that the elevated values of particulate mercury could contribute to explain the mercury anomaly in the Mediterranean fishes.

It is noteworthy that even in prestine aquatic systems, such as the aforementioned Krka river estuary at relatively narrow freshwater-seawater interface (of thickness not exceeding usually 50 cm) elevated mercury concentrations (up to ten times the usual 3.3 - 0.4 ng/l values) were found (BLINISKI *et al.*, 1992). Similar phenomena for mercury and other metals have been reported for other stratified or partly stratified Mediterranean estuaries and it is possible that similar mechanisms occur in the freshwater-seawater interface of the entire Northern Adriatic which is under the ecological influence of the river Po.

COSSA and MARTIN (1990) estimated the dissolved mercury inputs to the NW Mediterranean to 0.8 - 1.6 t /yr and the particulate mercury ones to 6.5 - 14 t /yr. It is noteworthy that GUIEU *et al* (1990) estimated that only 20% of the particulates (2 to 6 t /yr of mercury) may reach the open Mediterranean and influence the offshore deep sediments.

Sediments:

The levels of mercury in the Mediterranean marine sediments widely range from 0.01 to 1.5 µg /g, and even higher around "hot spots" corresponding to frequent natural geochemical anomalies in the sea or mouths of rivers draining catchment areas with similar anomalies (see e.g. 50 µg /g at Mt Amiata and the Idrija region). A systematic survey could probably identify more areas of this kind. Anthropogenic inputs also give rise to high mercury concentrations in areas affected by sewage outlets or industrial wastes particularly from chloroalkali plants and petrochemical industries (see for instance up to 200µg /g in the St Gille Lagoon, in Cagliari).

However, in most of these sites the extension of the high mercury levels is limited in space, not exceeding an area of few hundred km^2. Usually, background levels are reached at a distance of 10 to 20 km from the source. Nevertheless there is always the question of what levels sould be considered as "natural" background levels for the Mediterranean sediment.

Relatively few reliable data are available for comparisons on open sea sediment concentrations considering the fact that in most cases the sediment fraction used (grain sizes-mineralogy) and/or the extraction and analytical procedures employed differ among authors and only few of them report on analytical quality control. Nevertheless the data available show that 0.05 to 0.1 mg Hg-T /kg dw (dry weight) could be considered as "typical" Mediterranean background levels outside the "mercury belt". For the Adriatic sediments the lower levels reported for the clay silt fraction are usually in the range of 0.1 - 0.5 mg Hg-T/kg.

Another open question is the nature of the mechanism of biomethylation of mercury and its extent in intermittently anoxic Mediterranean sediments. It is known that its production is controlled by biological factors and it has been shown that bacteria and algae can transform mercury species.

Biota:

There are several investigations, all in agreement, confirming that Mediterranean fishes, particularly the pelagic species such as bluefin tunas, sardines, mackerel and anchovy as well as Mediterranean mammals, have considerably higher mercury levels than the same species from the North Atlantic or, even the North Sea. These statistically supported findings, in the light of the Minamata and Niigata cases of Japan, have raised the interest of National authorities and the wide public in order to (a) impose adequate measures and regulations for minimising the potential risk to humans from fish consumption to humans and (b) understand the reasons of this anomaly.

Based on the observation that methylmercury (MeHg) increases with age/size of the marine organism, BUFONI *et al* (1982) and BERNHARD (1985), proposed a simple model attributing the high Hg concentration in Mediterranean fish to higher mercury concentrations in plankton and in sea water from the Mediterranean and principally around the areas of mercury geochemical anomalies. However, data on seawater and plankton reveal no significant differences between samples collected in the Mediterranean and the Atlantic and despite recognised problems in analysis of water and plankton FOWLER (1985), ASTON and FOWLER (1985) and ASTON *et al* (1986) have criticized the model and its predictions.

Health risks:

From the point of view of health risks, mercury is at the top of the list for the Mediterranean. Methylmercury is surely the most important of the mercury toxic species. Several experiments have shown that inorganic mercury is taken up with relatively low efficiency and released with relative short biological half-time while MeHg is taken with very high efficiency and released with a half-time of years. The uptake through marine food is the dominant route of entry in the human organism.

Although the data available so far, are not sufficient to accurately assess the risk of mercury pollution (BERNHARD, 1988), several studies (BACCI *et al*, 1976; RIOLFATTI, 1977; NAUEN *et al*, 1983, etc) have shown that fish eaters, particularly residents of coastal areas, fishermen and their families have, in general, higher concentrations of total mercury in their hair, blood, urine and nails reaching the range of possible earliest effects (WHO, 1976). In cases where the fish food was coming from mercury-polluted areas, very high values were found (up to 110 µg Hg /g of hair). A high percentage of persons interviewed among them many children, seem to exceed their daily allowances.

The aforementioned findings, despite the uncertainties and the need for further systematic studies, justify the fact that several Mediterranean countries have laws which set a limit for the total mercury concentration in seafood (e.g. France 0.5 µg Hg-T /g fw, Italy 0.7 µg Hg-T /g fw), although it is known however that these laws are difficult to implement and therefore are rarely enforced at least regularly at local level. On the other hand, many fish and shellfish catches frequently do exceed these levels which presents a legal and, potentially, a public health problem with several socio-economic consequences.

Cadmium

Sources:

Cadmium enters the Mediterranean environment from natural (mineral ores) and anthropogenic sources. The former are mainly mines, metallurgical, electroplating or pigment industries discharging their wastes either directly or combined with domestic sewage, riverine inputs and runoff to the sea or to the atmosphere. Agricultural runoff may also contribute due to the cadmium impurities in the phosphorites used for the production of fertilizers.

Distribution, Concentrations:

<u>Atmosphere</u>:

The mean atmospheric concentrations over the W Mediterranean are between 0.36 and 0.60 ng /m^3 (ARNOLD *et al*, 1983; CHESTER *et al*, 1991; GUIEU 1991). The atmospheric flux in the same region was calculated by GUIEU *et al* (1991) to be 1.08 - 1.11 and 0.18 - 0.22 kg /km^2 /yr for dissolved and particulate cadmium respectively.

MARTIN *et al* (1991) reported 1.9 ± 2.0 kg /km^2 /yr total deposition at the Tour du Valat station and total atmospheric input of 42 t /yr, 39 t of which in the particulate form, compared to only 10 t /yr of the Rhone input. This means that 80% of the total cadmium input in the NW Mediterranean is transported via the atmosphere. These results were particularly surprising because (1) of the excessive contribution of the dry fallout (90 %), and (2) the cadmium deposition at the Tour du Valat station is much higher than that over two known polluted regions of Europe namely the North Sea and the Baltic. The authors suggested that Cd was primarily associated to coarser aerosol particles (with high deposition velocities) than other metals. Undoubtedly the understanding and confirmation of this phenomenon needs further investigation.

Seawater:

The concentrations of cadmium in the Mediterranean open sea fluctuate usually between 1 and 7 ng/l (BETHOUX *et al.* 1990). For the Alboran Sea and the Sicilian Channel, BOYLE *et al* (1984) and COPIN-MONTEGUT *et al* (1985) reported values ranging approximately between 5 and 10 ng /l, signaling also a gradual increase with depth which is an indication of nutrient-like behaviour.

Very recent data (MORLEY and BURTON, 1991; MARTIN *et al*, 1992) for the upper 500 m of the water column of the Central and North Western Mediterranean are in the same concentration range (5 to 12 ng /l), with minimum concentrations found in the Straight of Gibraltar (2ng /l), and a maximum in the bottom water of the Sicilian Channel (0.157 µg /l). In the Tyrrhenian Sea however, (NURNBERG, 1977), recent bottom values (for depth > 500 m) (STATHAM *et al*, 1985; MORLEY and BURTON, 1991), are one order of magnitude lower (6-9 ng /l) than those recorded at the surface a decade earlier.

The average values for total cadmium concentrations in surface waters of the Adriatic sea based on an extensive network of more than 50 stations sampled during the period 1989-1992 (M. BRANICA pers. communication) tend to increase northwards from <2 ng/l in the Strait of Otranto to 2 ng/l in the South Adriatic, 6 ng/l in the central and 16 ng/l in the North Adriatic respectively.

A provisional mass balance for Cd in the Western Mediterranean is given by MARTIN *et al*, 1992 (in press), based upon data collected during the EROS-2000 project and fluxes at Gibraltar and Sicily straits are given by BETHOUX *et al.* (1990) without corrections to account for the mixture of different water masses occuring in the inflow at Gibraltar. This balance gives as inputs : 2.7 µg /sec from Gibraltar, 9.5 from Sicily, 2.2 from rivers and 6.1 from the atmosphere, for a total of 20.5 µg /sec. Corresponding outputs are 9.6 µg /sec from Gibraltar and 8.5 from Sicily, i.e. a total of 18.1µg /sec.

The role of atmospheric inputs and the net supply of cadmium from the Eastern basin are stressed again as quite interesing features.

Sediments :

WHITEHEAD *et al* (1985) suggested the value of 0.15 µg/g dw of cadmium as background level for Mediterranean sediments, whereas the values reported by UNEP 1978 for offshore sediments range between 0.1 and 2.3 µg /g dw. Many workers using a variety of leaching reagents and analytical methodologies have reported Cd values for coastal sediments ranging between 0.05 and 5.6 µg /g dw with few exceptions in heavily polluted harbours and enclosed bays such as those of the western harbor in Alexandria or the Izmir Bay, were peak levels have reached 64 or 40 µg /g dw (UNEP, 1989). MARTINCIC *et al* (1989) reported Cd values ranging between 0.08 and 0.35 µg /g dw for surface silt-clay (<75 μm) sediments fraction from various, relatively unpolluted, areas of the Adriatic, whereas in the Sibenic harbour and industrial waste outflows much higher levels, up to 2.36 μg /g, were recorded. Very recent data from the NW Mediterranean (VAN HOOGSTRATEN and NOLTING, 1991) show that the highest values were determined along the western coast of France (leachable Cd 0.11 - 0.14 and total 0.21 - 2.21 μg /g). At the Rhone river mouth the leachable fraction had a value of 0.62 μg /g and the total was nearly 1.5 μg /g, whereas near the Ebro river mouth the concentrations were considerably lower but almost 96% of the total input was easily extractable, broadly of anthropogenic origin. The same authors reported values ranging between 0.07 and 0.1 μg /g for the leachable Cd fraction and 0.07 to 0.26 μg /g for the total cadmium in deep sea sediments of the NW Mediterranean. In conclusion sediments could be considered as good indicators of the evolution of cadmium pollution provided that minerological composition is also taken into account.

Biota:
A relatively large number of papers exist on Cd levels in seafood although not for all Mediterranean subregions. These levels are not, in general, significantly different from those observed in the NW Atlantic. Mussels, probably due to anthropogenic inputs have the highest cadmium levels followed by crustaceans (UNEP, 1989). The mean of all concentrations in mussels used as bioindicators in MED POL phase I excluding 5% of the highest values, was 120 μg /kg fw. The other MED POL bioindicator *M. barbatus* had considerably lower levels (mean of all samples in UNEP areas II, IV, VII, VIII, X) around 46 μg /kg fw. In most cases it is not stated if the mussels used are indigenous or transplanted and in most cases individual organs have not been studied. (For comments and suggestions see in the conclusions).

Risks to humans:

Terrestrial food (particularly kidneys and liver of farm animals) and cigarette smoking are, in general much more important sources of cadmium for humans than seafood, even for high sea food consumers. However, because the average cadmium intake is only slightly lower than the tolerable intake (DTWI) every effort should be made to avoid marine food with high cadmium levels and investigations are required for the identification and proper information of high risk groups or persons who ingest high amounts of cadmium.

Arsenic

Relatively very little information exist about arsenic in the Mediterranean.

Distribution, Concentrations:

Seawater:
Seawater concentrations for arsenic range in the Mediterranean from about 1 to 4 μg As-T /l. "Reactive As" ranges between 1 and 3.5 μg/l (STOEPPLER *et al*, 1981). MARTIN *et al* (1990) found the levels of arsenic in the Gulf of Lions to be between 1.5 and 1.7 μg /l

whereas the Rhone river average is 2.25 µg /l. This value is higher than the average European and American rivers (1.42 µg /l, according to ANDREAE *et al*, 1983), considerably higher than pristine rivers (0.8 µg /l), but still much lower than known polluted European rivers (such as Rhine, Sheldt, Tagus or Tamar) which have concentrations ranging between 4.5 and 45 µg /l.

In other seas As-T levels range from about 1 to 2 µg /l (review WHO, 1986), keeping always in mind that the lack of sea water standards for trace metals does not allow for safe intercomparisons. It is noteworthy that in seawater arsenic occurs both as arsenite (As III) and as arsenate (As V), the potential toxicity of which is insignificant compared to that of As (III).

Arsenic exhibits a nutrient-like behaviour following distributions analogous to those of phosphate that require particular further study in the Mediterranean.

Sediments:
Arsenic concentrations in coastal Mediterranean sediments can reach up to 10 µg /g (dw) (UNEP, 1989), which is comparable to concentrations determined in non-Mediterranean coastal sediments for which a range of 3 to 14 µg /g (dw) (WHO, 1986). Offshore Mediterranean sediments are reported to have higher levels of arsenic up to 120 µg /g (dw) compared to a world average of 20 to 30 µg /g.

Biota:
It is commonly known that arsenic, particularly in arthopods, may reach extremely high levels. Total arsenic (As-T) concentrations in marine fishes from the Mediterranean range between 8 and 70 µg /g fw with *Sepia officinalis* reaching up to 370 µg /g fw (STOEPPLER *et al*, 1981). "Typical levels" for fish are thought to be in the range of 1 to 10 µg /g fw (WHO, 1986), mostly in the As(V) oxidative state.

Lead

Sources:

Due to relatively increased volatility of lead and its compounds, particularly alkyl-lead, added as antiknocking in petrol (which is considered its major source) the principal route of transport to the marine environment is *via* the atmosphere. The increased variability of atmospheric concentrations is controlled mainly by precipitation events.

Input, Transport:

Riverine and direct inputs from sewage and industrial outfalls are also important. OREGIONI and FUKAI (1980) assessed the riverine input to the Mediterranean as approximately 3 10^3 tons /yr, whereas the atmospheric flux estimated by CHESSELET *et al* (1979) on the basis of lead concentrations in the Mediterranean aerosols and the average deposition over oceans was about 8 10^3 tons /yr based on lead concentrations in the Mediterranean aerosols and the average deposition over oceans. During the last few years a relatively good set of data on lead concentrations in Mediterranean aerosols (MARTIN *et al*,1989; REMOUDAKI *et al*,1991; CHESTER *et al*, 1991; GUIEU *et al*, 1991; MERMENTEAU and VEGLIA, 1992; MIGON and MORELLI, 1992 etc.), atmospheric fluxes and depositions have been obtained. The concentrations (all given in mg/m^3) varied widely (7.2 - 28.5 in Corsica; 60-70 over Monaco; 5.22 - 106.85 over the Ligurian Sea; 2.0-277 over Blanes). Similarly the deposition varied also (15 - 30 kg /km^2 /yr total Pb deposition over Corsica; 3- 3 - 18 kg /km^2 /yr total Pb deposition over the Ligurian Sea and 4.1 kg /km^2 /yr over the Gulf of Lions, 2.9 kg /km^2 /yr of which represented dry deposition). MARTIN *et al* (1989) calculated the mass balance of lead into the Mediterranean and found that the atmospheric input (1035 - 7245 t /yr) was several orders of magnitude higher than all other contibutions (9.32 - 66.24 t /yr river input, 1697 t /yr from the Strait of Gibraltar and 50 t /yr from the Black Sea).

Distribution, Concentrations:

Seawater:
UNEP (1989) reviewed the lead concentrations of the Mediterranean seawaters. For the Tyrhenian and W Mediterranean they ranged between approximately 0.02 and 0.09 µg/l and in the N.W Mediterranean between 0.05 - 0.14 µg /l. Recent data from MORLEY *et al* (1990) and MORLEY and BURTON (1991) give an average of 0.02 ± 0.015 µg/l for the deep (>500m) waters of the N.W Mediterranean, while the surface waters contain around 0.04 µg /l. North, Central and South Adriatic exhibit 0.057, 0.046 and 0.029 µg /l lead concentrations respectively (BRANICA *et al*, 1993). It is noteworthy that the background oceanic levels of lead range between 0.005 and 0.015 µg /l (GESAMP, 1985).

Sediments:
There are many reports on Pb concentrations in Mediterranean, mostly coastal, sediments reviewed in SCOULLOS (1986). Among them few particularly high ones near "hot spots": Cortiou, Marseille 1250 µg /g; Thermaikos Gulf, Greece 1800 µg /g (not far from an alkyl- lead producing industry, now closed); Cartagena, Spain 938 µg/g; Gulf of Elefsis, Greece 600µg /g; Izmir Bay, Turkey 240 µg /g, Hazine-Sibenic 164 µg /g etc. However, even within the same Gulfs, in relatively small distance from these high spots the levels drop by one or two orders of magnitude. WHITEHEAD *et al* (1985) suggested the value of 25 µg /g as background. However SCOULLOS (1986) examining several subsurface samples has established the Mediterranean preindustrial background levels of total lead in the <63 µm fraction to be approximately 10 µg /g. The same author using chemical and physical partitioning methods showed that in enclosed bays such as the Gulf of Elefsis the major lead fraction (approx. 40%) was associated with organic matter and sulphides, followed by that connected with iron and manganese coatings and carbonates (30%), whereas a small, but ecologically significant faction of 3-4 % is in a readily exchangable form easily released to the overlying waters under favorable conditions.

VAN HOOGSTRATEN and NOLTING (1991) determined the 0.5N HCl leachable lead concentrations in sediments collected from the French coast of the Gulf of Lions and found them to range between 19.3 and 23.2 µg /g whereas the range along the Spanish coast was between 8.8 and 12.8 µg /g. Relatively elevated concentrations were found at surface sediments of the deep NW Mediterranean (11.7- 11.5 µg /g) which decrease to <9.00 µg /g downcore (NOLTING and HELDER, 1991). This finding, combined with the high magnetic measurements found in the same depth intervals by SCOULLOS and ZERI (1991), suggests that its origin is anthropogenic transported via the atmosphere (SCOULLOS and ZERI, 1993; NOLTING and HELDER, 1991).

Biota:

The lack of reliable Pb data for biota, which is due to the low levels of Pb, and to the high degree of potential contaminations to which the analyses are subject, make it difficult to establish typical Mediterranean lead levels in organisms. However, it is found that mussels (*Mytilus galoprovinciallis*) have the highest concentrations of lead in their tissue (mean of all lead levels 800µg /kg fw) (review: UNEP/FAO, 1986; ICES, 1974, 1977,1977a). Lead levels in *Mullus barbatus* are lower (mean of all samples in UNEP Mediterranean subregions II and X: 70 µg /kg fw) whereas in tuna (*Thunnus thynnus*) the mean is 117 µg /kg fw.

Zinc - Copper

Sources, Transport, Fate:

Geologic weathering, erosion and dissolution of the earth's crust release worldwide 720 000 tons/yr of zinc (GESAMP, 1976), mainly through rivers runoff and atmospheric particles; however, the underwater, hydrothermal and volcanic contributions have not been studied in the Mediterranean. Mining, metallurgical, electroplating, viscose, rayon and fibre dye, pulp and paper production, etc., involve zinc, whereas copper comes from industries where it is used in alloys, as catalyst, in antifouling paints and in wood preservation and the metallurgical, jewellery wiring, electroplating and electric circuits industries. Combustion of fossil fuels and waste incineration release them to the environment. Zinc and copper are enriched in suspended matter carried by rivers and waste waters as well as in treated sewage sludges.

Inputs:

UNEP/ECE/UNIDO/FAO/UNESCO/WHO/IAEA (1984) estimated the total annual zinc inputs to the Mediterranean by rivers to 18 x 10^3 tons, 14 x 10^3 of which were considered as deriving from anthropogenic activities and 4 x 10^3 tons as background. The direct domestic and industrial inputs were assessed to 1.9 x 10^3 and 5 x 10^3 tons respectively. Recently DORTEN *et al* (1991) have made new assessments for the riverine and other inputs and the emerging new picture differs considerably from the one held until recently.

The Mediterranean seems to receive annually natural inputs of 23.5 x 10^3 tons of zinc and 9.2 x 10^3 tons of copper from the Atlantic and another 0.08-1.3 x 10^3 tons of zinc and 0.5 - 11 x 10^3 tons of copper from Bosphorus. The annual atmospheric inputs (mixed) of zinc were estimated to 42.5 x 10^3 tons and copper to 5 - 10 x 10^3 tons, respectively, with a most probable mean approaching the lower estimate. The annual load estimated by DORTEN *et al* (1991) was 0.6 - 1.6 x 10^3 for zinc and 0.2 - 0.6 x 10^3 tons for copper. The direct domestic and industrial discharges of zinc are estimated to 2.3 x 10^3 and 6 x 10^3 tons per year respectively. It is clear that the predominant input is atmospheric.

Distribution, Concentrations:

The average zinc level of Mediterranean aerosols is around 20 ng /m^3 although values of approximately 9 ng /m^3 and 6 ng /m^3 have been reported by GUERZONI *et al* (1986) for the Eastern Mediterranean and South Adriatic, respectively. The majority of zinc measurements far from point sources range between 0.1 and 8 µg /l.

Seawater:

For both zinc and copper concentrations, the reader will find up to date data in the work of BETHOUX *et al.* (1990). HUYNG-NGOC and FUKAI (1979) reported as average dissolved zinc in the Mediterranean the concentration of 2 ± 0.2 µg /l. Recent findings by MORLEY *et al* (1991) provide an overall range of concentrations for offshore seawaters between 0.15 and 0.24 µg /l. BRANICA *et al* (pers. communication) found average total surface concentration ranging from 0.41 µg /l in the N. Adriatic to 0.09 µg/l in the S. Adriatic wheras in the Strait of Otranto values even below 0.03 µg /l were recorded. Concentrations in coastal waters, and particularly in harbours or areas affected by industrial and sewage outfalls, are several orders of magnitude higher, reaching in extreme cases 450 µg /l. It appears that results of earlier studies may have been affected significantly, to varying degrees, by contamination problems.

Copper concentrations of open waters ranged from less than 0.03 to 3 µg /l. More recent values for the Mediterranean (UNEP 1978,1986; NURNBERG, 1983; KREMLING and PETERSON, 1981; LAMMOND *et al.* 1983; BOYLE *et al*, 1985; MORLEY, 1990) for the Mediterranean waters range between 0.06 and 0.25 µg /l. In the Strait of Otranto concentrations as low as 0.03 µg /l were recorded whereas in the rest of the Adriatic the levels increase from the south northwards from 0.09 to 0.41 µg /l (BRANICA *et al,* pers. communication). The highest values in polluted areas reach the levels of 10,50 or 70 µg /l near mines (eg. Lavrion, Greece; SCOULLOS 1981), in polluted parts of the Adriatic (GRANCINI, 1976) or harbours (Alexandria; EL-SAYED, 1981).

Sediments:

Similarly zinc in polluted sediments may reach extremely high values at the upper top layers of the sediment column (eg in Spain and other coasts up to 6480 µg /g; Venice lagoons 5930 µg /g; Marseille 2550 µg /g; Gulf of Elefsis 2100 µg /g). Most of these sites also contain the highest copper concentrations with maxima reported for W. Harbour Alexandria (1890 µg /g) and Izmir Bay (870 µg /g).

Offshore sediments contain levels between 20 and 80 µg /g for zinc (FRIGNIANI, 1983 etc) and around 42 for copper (SHAW and BUSH, 1978), whereas coastal background concentrations of total zinc range in the clay-silt fraction are approximately 20 µg /g dw (SCOULLOS, 1981) and for total copper in the range of 10 to 30 µg /g dw (SCOULLOS, 1979; CAUWET and MONACO, 1983; DONAZZOLO, 1984).

Biota:

Microplankton concentrations for zinc are around 200 µg /g dw (usual fluctuation between 100 and 400 µg /g dw) and for copper between 15 and 40 µg /g (FOWLER, 1986; HARDSTEDF *et al*, 1980). Some very high values were found in *Acartia clausi* (1270 µg /g for zinc and 55.3 µg /g for copper; ZAFIROPOULOS and GRIMANIS, 1970). Zinc and copper was found to decrease from phytoplankton (zinc 262 µg /g, copper 34 µg /g) to copepods (zinc 227 µg /g, copper 24.1 µg /g) and from copepods to crustaceans and pelagic carnivores.

Subregional mean concentrations of zinc in *M. galloprovincialis* range from 17 to 45 μg /g fw. Overall ranges are between 3.15 and 97.7 μg /g, whereas the Mediterranean mean is 27 μg /g fw. Copper concentrations are considerably lower. The Mediterranean mean is 1.3 μg /g fw and the subregional means range between 1.0 to 1.9 μg /g fw (UNEP/FAO, 1986), with the highest values reported from the Ligurian sea and off the Turkish coast.

In *Mullus barbatus* zinc is also present at much higher concentrations (3.9 - 5.1 μg /g fw) than copper (0.38 - 0.93 μg/g fw), taking into account mean subregional concentrations, excluding the upper 5% of individual values. In some regions (eg. off the coast of Israel) and for some species (eg. *Saurida undosquamis*) very high values have been reported (30 μg /g for zinc and 8 μg /g for copper) but these are characterised as untypical.

ORGANOTIN COMPOUNDS - INORGANIC TIN

Sources, Transport:

There is no information on the actual load of organotin compounds discharged into the Mediterranean. The major pollution potential arise from the use of triorganotin compounds (tributyltin - TBT, triphenyltin - TPT) as antifouling agents in cooling - water pipes of industries, and in paints for boats, ships and marine structures from which they are directly released into the seawater.

A minor source of diorganotin compounds could be the use of such compounds as stabilizers in rigid PVC and other plastic materials that are disposed and find their way to beaches and the sea as marine litter. However, due to their low volatility, UV light instability and high soil affinity, the release rate of dibutyltin compounds from plastic matrices to the seawater via runoff or atmospheric transport is very low. Efficient incineration of wastes containing materials produced by means of catalysis by organotin derivatives (such as polyurethane foams and silicone elastomers) is assumed to transform organotins into inorganic tin (BOCK, 1981).

Triphenyltin (TPT) derivatives used as biocides in agriculture by dispersive application to land, could reach the sea by means of leaching and runoff.

Fate:

From data reported by ALZIEU *et al* (1986), it appears that organotin compounds and bioavailable inorganic tin are not very persistent chemicals under natural environmental conditions. Inorganic tin can be biomethylated within the marine environment producing more toxic and more mobile species (THOMPSON *et al*, 1985). In estuarine waters LEE *et al* (1987) showed that, besides sunlight, microbial activity and microalgae when present in high concentrations play a significant role in TBT degradation producing mono- or di-butyltin derivatives, as well as mono-, di- and tri-methyltin derivatives.

TBT and TPT have a higher affinity for sediments than for water, therefore sediments are their main reservoir. Due to its lipophylic nature, TBT is accumulated by marine organisms (e.g. fish, molluscs) to levels considerably higher than those in the surrounding water.

Distribution, Concentrations:

Seawater:

Higher levels of organotin compounds, particularly of TPT, occur in the surface water microlayer due to their lipophylic properties (CLEARY and STEBBING, 1987). Mono- and di-butyl compounds are present in the seawater in lower concentrations than TBT. There are, however, very limited data on triorganotin concentrations in Mediterranean waters. Inorganic tin may be present in rainwater, freshwater and seawater within the range 0.1 - 1 ng /l. Methyltin concentrations vary from <0.01 - 1090 ng Sn /l in water samples, with the higher values at sites heavily contaminated by TBT and its derivatives (MAGUIRE *et al*, 1982) such as ports and marinas. In estuarine and marine waters no other organic species of tin such as phenyl or cyclohexyl derivatives have been reported (THOMPSON *et al*, 1985).

The main data for Mediterranean waters were obtained through the MED POL FAO/UNEP/IAEA/WHO Pilot survey of organotins. The results of this survey show extremely high levels of TBT (11930 - 12150 ng /l) in water samples collected at the Leghorn power plant outlet (Italy). As far as harbours are concerned Leghorn (Italy) and Mersin (Turkey) (936 ng /l) are the most contaminated sites known. In marinas, the highest level of TBT was recorded at Cecina, Italy (3930 ng /l), however, the majority of values ranged between 100 and 1000 ng /l. The mariculture areas sampled on the French coast exhibited less contamination by TBT (from <2 to 17 ng /l) (FAO/UNEP/IAEA/WHO, 1988).

Concentrations of samples collected in open waters off the Italian coast and elsewhere, were below the detection limits.

Sediments:

All sediment samples included in the FAO/UNEP/IAEA/WHO survey were collected in Alexandria coastal belt and contained inorganic tin ranging from 310-5200 ng /g, and tributyltin ranging from 30 - 1375 ng /g. The organic carbon content, together with % clay content and salinity (UNGER *et al.*, 1987), plays a significant role in TBT partitioning between sediment and water.

Biota:

The main types of organotin compounds in fish and shellfish from contaminated environments are the tri-, di- and monobutyltin compounds. Levels of TBT in oysters and fish can exceed 1000 µg TBT /kg fw (ALZIEU *et al*, 1986; SHORT and THROWER, 1986) either in highly polluted areas or in aquacultures using cages of TBT-treated netting (DAVIES and MCKIE, 1987). Some marine organisms like Pacific oysters (*Crassostrea gigas*) can accumulate organotin compounds, particularly TBT, up to 16000 - fold in respect to the seawater level (WALDOCK *et al*, 1983).

Recent laboratory and field experiments have further confirmed that tributyltin is harmful to marine organisms at extremely low concentrations and potentially harmful to man via the food chain (FAO/UNEP/IAEA/WHO, 1988).

ORGANOHALOGEN COMPOUNDS

Sources:

Organohalogen comprise a wide range of substances (over 1000 being potential marine contaminants). Approximately 20% of these are pesticides such as DDT, to which the majority of environmental information available for the Mediterranean region refers. Little attention has been focused on industrial compounds with the exception of polychlorinated biphenyls (PCBs). Most of the information available for the Mediterranean was reviewed by FOWLER (1985, 1987)) and by UNEP (1990).

Consumption figures collected for the 1973/1976 period, during MED POL X, show a total pesticide consumption in the Mediterranean watershed (excluding Albania, Algeria, France, Malta, Monaco, Morocco, Yugoslavia and five regions of Italy) of about 5.7 x 10^3 tons/year. The actual figure for the entire Mediterranean at the time was thought to be at least double. However, Cyprus, Egypt, Greece, Israel, Italy, Libya and Turkey reported to FAO that in 1985 no chlorinated pesticides were used.

Among the chlorinated pesticides is DDT and its metabolites DDD and DDE, HCH (hexachlorocyclohexane) which is considered one of the less persistent organochlorine compounds, and its gamma-isomer known as lindane which is the one normally used as an agricultural pesticide. Aldrin and its epoxide dieldrin are also used as pesticides, whereas endrin, a stereoisomer of dieldrin, is the most toxic of the chlorinated pesticides. Some other chlorinated compounds used as insecticides and fungicides are hexachlorobenzene (HCB), heptachlor and its metabolite heptachlor epoxide. BURNS *et al* (1985) noted the increasing importance for the Mediterranean environment of lindane and hexachlorobenzene in recent years.

PCBs are mixtures of chlorinates biphenyl isomers and homologues. Impurities found in commercial PCBs can include polychlorinated naphthalenes (PCNs) and polychlorinated dibenzofurans (PCDFs). Despite the temporal and geographical limitations of data available there is strong evidence that the input of PCBs in recent years was reduced after the implementation of restrictions on industrial discharges by the Mediterranean EC and other countries. Nevertheless PCBs remain a major class of halogenated contaminants in the Mediterranean still used throughout the Mediterranean region and produced industrially in some Mediterranean countries. GEYER *et al* (1984) reported production figures of several thousand tons for 1980 (eg. for France 6557 m tons, Italy 1479 m tons, and Spain 1241 m tons). PCBs are used mainly in capacitors and tranformers.

Input, Transport:

Halogenated hydrocarbons enter the Mediterranean primarily via the atmosphere or directly through run-off, river, sewage or industrial discharges. Concentrations of PCBs reported in the atmosphere of the Mediterranean sea during 1974 (0.23 ng /m^3) were similar to values reported for the Pacific (0.19 - 0.32 ng /m^3), or the Antarctic ocean (0.11 - 0.25ng /m^3).

Early UNEP (1984) estimates assessed the total input of organochlorine pesticides to the Mediterranean carried by surface run-off either directly or through rivers to be about 90 t /yr (range 50-200). 65% of this load is received by the W Mediterranean and

Adriatic, out of which 17% or 14.9 t /yr was discharged in the NW basin mainly by the Rhone and Ebro rivers. BURNS and VILLENEUVE (1987) taking into account only the Rhone river concentration have estimated the annual input for total PCBs to 3.6 tons and 0.2 tons in particulate and dissolved phase, respectively, whereas in the most recent assessment of TOLOSA *et al* (1991), based on analyses of sediments and fluxes, the inputs of organochlorinated compounds in the NW Mediterranean deltaic systems (combined Rhone and Ebro, the latter contributing approximately 1/10 of the total) are 1.8 t /yr PCBs (expressed as Arochlor 1260 equivalent; 4.5 t /yr), 4 t /yr DDT and 0.5 t /yr HCB.

Comparison of atmospheric and riverine input rates of organohalogen compounds to the World Ocean, made by GESAMP (1989), shows that pollution inputs through the atmosphere is much more important (0.72 µg /m^2 /yr) than that through river discharges (0.1-0.2 µg /m^2 /yr). For ΣDDT the atmospheric input seems to represent almost 98% of the total.

Fate:

There is a strong tendency for non-polar organic pollutants like DDT (with low solubility in water) to become associated with other organic phases like the lipid tissue of organisms (OLSEN *et al*, 1982), oils in sea surface films (DUCE *et al*, 1972), dissolved or particulate humic substances in seawater (PIERCE *et al*, 1974) or organic detritus in sediments (BOPP, 1979). In addition in near shore coastal areas highly reactive pollutants like organohalogen compounds are absorbed to a lesser extent onto suspended particles and are consequently removed from the water column to the sediment. Annual atmospheric and vertical fluxes in the Mediterranean range widely (see Table I).

Table I

Annual Fluxes for Halogenated Hydrocarbons in the Mediterranean in µg/m^2/yr

	HCB	PCB	Arochlor 1260	DDT	Reference
Atmospheric Deposition Fluxes					
Open Sea	0.12	0.77	1.9	0.92	Tolosa et al, 1991
Rhone Estuary	31	107	273	249	Tolosa et al, 1991
Vertical Fluxes in the Water Column					
Ligurian		103			Fowler et al, 1979
Gulf of Lions	0.004-7.9	3.5-474.5	0.095-48.2		Fowler et al, 1990

Indeed for the vertical transport of PCBs in the water column biogenic particles, like euphausid feacal pellets, play a significant role (ELDER and FOWLER, 1977).

Concentrations of chlorinated hydrocarbons in pelagic organisms (on a whole organism, dry weight basis), reported by FOWLER and ELDER (1978) suggested that PCBs and pp' DDE were not biomagnified in the particular food chains studied.

Distribution, Concentrations:

Seawater:
The most comprehensive coastal surveys have been caried out in the NW Mediterranean. The highest concentrations of chlorinated hydrocarbons (38 ng /l) were found near the Rhone river mouth (ELDER, 1976). Similar results were reported for the Var river estuary (BURNS and VILLENEUVE, 1982) and the Huveaune river outfall off Marseilles, where RAYBAND (1972) reported ΣDDT concentrations of approximately 150 µg /l in the surface microlayer. Roughly 0.5 m below the surface these levels dropped to 0.19 µg /l. This zone is known to be polluted by pesticides and PCBs and values in waters further from this source are usually lower. In general, surface microlayer also in other regions (eg. see Adriatic) was found to contain high levels of PCBs (597 ng /l). At the Tiber estuary the contamination of waters by PCBs was reported as increasing with increasing distance from the shore (PUCCETTI and LEONI, 1980). It is possible that some microorganisms in the water act as microbiological decontaminating agents. The same authors have reported the highest PCB concentrations for polluted Ligurian sea waters (50 - 548 ng /l).

In the open sea, the levels of PCBs in near surface waters are not very much different from those in deep layers even more than 2 km deep. The data reported by VILLENEUVE *et al* (1981) from surveys covering the period 1977-1979, range between 0.1 and 2.5 ng /l with a reasonably safe "mean" concentration of approximately 0.7 ng /l. The data show some systematic regional differences. In the Aegean, Ionian and Northern Adriatic, even in early surveys, ELDER and VILLENEUVE (1977) and PICER and PICER (1979) give systematically lower concentrations quite often below the detection limits of 0.05 ng DDT /l or 0.1 ng PCB /l with peak values not exceeding 2 ng /l. Lindane levels offshore in the eastern basin ranged from 0.06 to 0.12 ng /l.
Keeping in mind that intercalibration exercises show a large dispersion of results and the analytical uncertainty of the measurements of chlorinated hydrocarbons in all marine samples makes the evaluation of and comparison between the data of different authors or different periods very difficult, it is perhaps noteworthy that the aforementioned value of 0.7 ng /l is approximately three times lower than the average of 2.0 ng /l (range 0.2 - 8.6 ng /l) obtained by the same group (ELDER and VILLENEUVE, 1977) for 80 samples collected from the same region in 1975. According to the authors, this finding suggest a genuine decrease during that period.

In the UNEP 1990 report (No 39), an attempt was made to normalize individual values by using "concentration factors" and ratios for water, sediment, mussels and mullet. However, it was recognized that there were still large differences for many "concentration factors" (eg only 300 for DDT between sediment/water in area IV but 122000 for area VIII). In many areas there are no measurements in all matrices. Therefore a further normalization was used allowing to classify the various Mediterranean subregions as follows on the basis of both DDT and PCBs: II > VIII > IV > V > VI > III > IX > X > VII. The reliability of this classification is higher for the first five subregions, where the available number of matrices used were similar (9-12). For the last four subregions only 3-5 matrices were available (for the numbers see Table II).

Table II
Mediterranean Subregions

I	Alboran Sea	VI	Ionian Sea
II	NW Mediterranean	VII	Central Mediterranean
III	Algero-Provencial Basin	VIII	Aegean Sea
IV	Tyrrhenian Sea	IX	NE Mediterranean
V	Adriatic Sea	X	Levantine Basin

Sediments:
Several investigations have been carried out in Mediterranean sediments, mostly concerning coastal areas where "hot spots" have been identified particularly near sewage outfalls such as those of Marseille (up to 16000 ng PCBs /g dw) and Athens (up to 800 ng PCBs /g dw) or near larger towns such as Nice (up to 1165 ng PCBs /g dw), Naples (up to 3200 g PCBs /g dw) and Augusta (up to 460 g PCBs /g dw) (FOWLER, 1986, JEFTIC *et al*, 1990). In most cases these high concentrations dropped to background levels in a distance of some kilometers from the source. Concentrations in the top centimeter of 12 open sea cores sampled in the Eastern and Western Mediterranean between 1977-79 ranged widely from 0.8 to 9.0 ng PCBs /g dw, whereas in general the lowest concentrations determined for PCBs, DDT or HCB in sediments of the central Mediterranean was around 1 ng /g and the maximum around 80 ng /g.

Biota:
Means of PCBs available in marine organisms range widely from 1.5 to 815 ng PCBs/g fw. More numerous data are available only for the mussel and the red mullet. In both mussel and mullet the NW Mediterranean (MED POL subregion II) seems to have the highest concentrations. In mullet the lowest level (means and maxima) are observed in areas IX and X. Means of DDT range from 0.1 to 343 ng /g fw, DDT from 0.4 to 325 ng /g, DDE from 1.5 to 600 ng /g, with tuna fish (*Thunnus thynnus*) having the highest concentrations. Dieldrin means range from 0.4 to 6.2 ng /g fw, Aldrin means from 0.2 to 2 ng /g fw, Hexachlorocyclohexane from 0.7 to 20 ng /g fw and Lindane from 0.4 to 19 ng /g fw. Area X seems to have the lowest mean and lowest maximum levels (UNEP, 1990).

Environmental levels of DDT are considered to be not high enough to cause a risk to marine birds (through their well known effects on the reproduction). The levels of PCB and other organohalogens are likewise unlikely to cause adverse and significant effects on marine communities, at least on a regional level. However, significantly high levels of organohalogens (including DDT and PCBs) have been found in a number of localities, especially those exposed to major sewage outfals, such as at Marseille, the Bay of Naples, the Gulf of Venice, the Rijeka Bay and the Saronicos Bay.

Based on animal experiments, it is prudent to regard PCB and DDT as potential human carcinogens. These two contaminants increase the cancer risk through consumption of sea food, even when the environmental levels are low and even in the case of low fish consumers (ie, those eating one meal of fish per week). It has been recently estimated (UNEP, 1990) that the levels of PCBs and DDT are in some areas, sufficiently high to increase the cancer risk of all consumers who eat at least one fish meal per week from the contaminated stock, from 1 in 100,000 to 2-4 in 1,000.

Human consumption of marine organisms contaminated by municipal sewage sludges with high concentrations of DDT or PCBs, dumped off the Mediterranean coast may pose significant health risks. Risk models have been developed and applied to estimate such risks in the case of certain regions in the U.S.A. (LIPTON, 1989). WILLIAMS and KRUEGER (1989) showed that relatively high risks are associated with the consumption of fish from Puget Sound. There is a need to estimate such risks for certain Mediterranean 'hot spots' taking into consideration the bioconcentration of such contaminants, commercial fish landings, and seafood consumption in the particular locality.

ORGANOPHOSPHORUS PESTICIDES

Though organophosphorus pesticides are generally considered to be biodegradable, their presence in the Mediterranean coastal waters have been identified near point sources which discharge directly in the sea. Reported levels in sea water as well as in some biota (fish from the coast of Spain) were found to be very low and unlikely to pose a health hazard to man through consumption of seafood. On the other hand, the data set on the levels of these contaminants within the Mediterranean basin are extremely limited both in geographical and spatial extent, and therefore it is presently impossible to confirm beyond any reasonable doubt that such contaminants may not constitute a hazard to human health or to the health of marine organisms and their communities.

PETROLEUM HYDROCARBONS

Sources, Transport:

The Mediterranean is bordered to the north by major oil consumers. Europe, in general, is the world's second largest consumer of oil and a major oil importer. In the east and south, in the Middle East and North Africa, we have the major oil producers.

Widespread exploration for, and in many places commercial production of oil (of the order of 130 million tons, in 1975) is taking place off Western Spain, Tunisia, Libya, Sicily, Egypt and in the Adriatic, the Ionian and north Aegean seas. At the same time (1975) the amount of oil transport to coastal countries through the basin was approximately 40% of the total maritime transport of oil all over the world by sea, 350 million tons, 150 million tons of which were transported from the countries of North Africa.

Even if today only 20%-25% of the world oil production transported by ships(of the order of 3,5-4 x 10^9 tons/y) passes through the Mediterranean, the fact that the latter represents less than 1/100 of the surface of the world Ocean explains why this sea is so heavily polluted by oil, at least in some parts. Moreover most of the Mediterranean ports still lack reception facilities for oily waste-waters.

As the usual percentage of loss of oil to the sea from ships and loading / unloading operations is very roughly 0.04 - 0.1% (SCOULLOS, 1987), one could figure an approximate amount of 150 000 - 350 000 tons of oil discharged to the Mediterranean annually only by ships. Deliberate discharges, accidents, sewage and industrial discharges, riverine and runoff inputs and, quite important atmospheric depositions and offshore drilling activities are thought to increase the overall annual load received by the Mediterranean to the vicinity of 1 m tons (BRIAND, 1992), although these can only be estimates in the absence of adequate, accurate data.

Most of the oil entering the sea forms emulsions and sinks to the sediment (~36%); considerable amounts evaporate or form tar balls and strands, whereas a significant percentage (~1/3 of it) biodegrades slowly in the surface film, the water column and the sediment within a period of several months.

Distribution, Concentrations:

Seawater:
Dissolved/dispersed petroleum hydrocarbons (DDPH) in offshore Mediterranean waters have concentrations below 10 µg DDPH /l, but very high concentrations are also found occasionally in the open sea (UNEP, 1990). GC-determination on open sea samples (Phycemed cruises) showed that the petrogenic Hydrocarbons' aliphatic fraction ranged between 1.1 and 4.5 µg /l and the aromatic one from 0.1 to 0.8 µg /l. Near industrialized areas or river mouths, concentrations are frequently well above 10 µg DDPH /l throughout the Mediterranean. In the inner part of the harbour of Taranto (Mar Piccolo) concentrations varried between 0.1 and 36 µg /l. Polluted parts of the Adriatic sea have levels as high as 50 µg /l (the IR-determinations give a much higher level of 1100 µg /l; UNEP, 1990) whereas in the Eastern Mediterranean 10 - 20 µg /l and occasionally even higher (see 25 - 40 µg /l near Cyprus or the coast of Turkey) were reported near refineries, river mouths or main ship lanes. Nevertheless the usual levels in the open Aegean and Cretan sea are between 0.14 and 1.4 µg /l and near the coast rarely exceed 3 µg /l (MIMICOS, 1980, SCOULLOS *et al*, 1982).

Data on floating tar are limited and show mean levels ranging from 0.5 to 16 mg/m^2 in offshore areas and much higher concentrations in nearshore waters (10 to 100 mg/m^2). The Eastern basin appears most heavily polluted by tars but virtualy all data come from this part of the Mediterranean (review: UNEP/IMO/IOC, 1987; UNEP, 1990).

Sediments:
Aliphatic petroleum hydrocarbon data in sediments range from 1 to 62 µg/g sediment and aromatics from 2 to 66 µg /g sediment along the Spanish coast outside harbours, oil terminals and river mouths. Values reported from coastal sediments of the Eastern Mediterraneanare typically between 5.9 to 23.6 µg /g ww aromatics, in the Gulf of Gera, Lesvos isl., Greece (SCOULLOS *et al*, 1982). Two samples from the central part of the western basin suggest background levels in the order of 1.2 µg /g aliphatics and 0.6 µg /g aromatics. Offshore sediments from Cyprus (90 m depth) ranged from 0.114 to 1.35 µg /g and somewhat lower values are reported from Iskenderun Bay, Turkey. Too few data are available to obtain a distribution pattern of petroleum hydrocarbons in the Mediterranean sediments (review: UNEP/IMO/IOC, 1987).

Biota:

Only very few studies on petroleum hydrocarbons in marine organisms are available. Mussels collected near Palamos, Barcelona and in the Ebro Delta (8 to 3200 µg /g dw in the saturate fraction) are much higher concentrations than in fishes. *Mullus barbatus* (5.8 to 22 µg /g) has somewhat higher concentrations than pelagic fishes such as *Merluccius* sp., *Trachurus* sp. and *Engraulis encrasicholus* (review: UNEP/IMO/IOC, 1987).

RADIOACTIVE SUBSTANCES

Sources:

The sources of radioactivite substances are well-defined ones such as nuclear power-plants, fuel reprocessing plants, etc. and the diffuse sources such as atmospheric fall-out, river run-off etc.... The known point sources on the Mediterranean coastline (Rhone and Ebro rivers) are not particularly significant when considered at the regional level. However, at the local level they may become quite important.

Atmospheric fallout (UNEP,1992) is by far the most important source of most radionuclides (ie 10 out of 12 PBq for Cs137). This implies that a significant proportion of the radionuclides reaching the Mediterranean sea originate from outside this region. For example, Chernobyl fallout increased the Cs-137 deposition by approx. 25-40%., though rates of deposition differed tremendously with area. High Cs- 137 levels in some biota, as expected, immediately after the Chernobyl accident, may have decreased to nearly normal levels by 1989.

The effects of artificial radionuclides on marine biota are considered to be negligible, taking in the account the actual reported levels in the environment and the levels at which effects are expected to occur according to laboratory and field data (from Sellafield, U.K.)

Quantitative assessment of risk is impossible at this stage of our knowledge of levels, and population habits. Nevertheless it is believed that the increased radiation risk for man may correspond to 1 case of severe harm in one million.

LITTER

Sources:

Persistent litter in the marine environment consists of a large variety of materials: plastic, metal, wood, glass, rubber, styrofoam, cloth and others. The sources of marine litter input are: i) litter reaching the beach as drainage from land or ii) litter left by beach users and/or by construction contractors as building debris, iii) litter discarded from ships ("marine-based") and found mainly near the shipping lanes or harbours. It seems that in the Mediterranean land-based litter is more abundant than marine - based (GOLIK and GERTNER,1989, 1991; IOC/UNEP/FAO, 1989), whereas in the Atlantic

(W. European beaches) and the Pacific litter was found to originate mainly from ships or from fishing activities (MERELL, 1984; VAUK and SCHREY, 1987, DIXON and COOKE, 1977; DIXON and DIXON, 1980, 1983).

Input, Transport:
Although it is very difficult to obtain quantitative information on the input of litter to the Mediterranean, several attempts have been made in the past. MATTHEWS (1975) concludes that the marine-based litter in the Mediterranean is mainly cargo associated, trash discarded from merchant ships, and it is estimated to be 285 tons/ship/year. An early estimate gives a global figure of solid materials of human origin accidently or deliberately discharged from the world fleet of vessels (NAS, 1975) of approximately 6 million tons/year. This may be an underestimate since it is based on old data (1970's), which excluded some Mediterranean countries. The results of an extended study gave an estimate of 100 pieces of liter per 100 m^2 of shore line per year, assuming 20% of the world's shipping passes through the Mediterranean (KOCBAS, 1989). From a survey of floating mega-litter (items >2.5 cm) was found that at a site 64 km south west of Malta an overall density of 2000 items per km^2 were found. Approximately 70% of these objects were fabricated from plastics including cups, sheeting, bottles and smaller fragments. Other items included nylon rope too (MORRIS, 1980). MC COY (1988), using the same method from a stationary ship in the Ionian found only 0.12 pieces km^2, and he attributed this observation to the fact that his ship was located away from the usual ship lanes. Other surveys included a 1419 km^2 study area some 350 km southwest of Crete. A total of 20 items of megalitter was recovered. Extrapolation of those results to the entire Mediterranean gave an order of magnitude of 3.6 10^6 objects afloat per day. Plastic material have also been recovered in trawl catches in the same region with an order of magnitude of 100 kg km^2 (IOC, 1988).

The effect of waves usually drive litter landward whereas winds and currents have various consequences, sometimes seasonal, which became obvious in the distributions found by LOIZIDES (1989) on two beaches of Cyprus and by GOLIK and GERTNER (1989) on the coast of Israel. Another example of the wind effect on litter distribution is given by MARINO *et al* (1989) from a survey off the N.E. coast of Spain.

In terms of its fate, litter can be classified into 3 types: i) coastal litter, ii) floating litter and iii) sea-bed litter.

i) From a survey carried out on several beaches of Spain, Sicily, Cyprus and Iarael it was found that litter concentration has a wide range of values: 0.53 - 1105 pieces / frontal meter of beach. Sampling of more Mediterranean coastlines is required in order to get a better estimate on coastal litter level. Perhaps the most extensive survey has been carried out by HELMEPA between 1990 and 1992, covering some 400 km of representative greek coastlines. Although the data are still under treatment (HELMEPA, 1990; SCOULLOS *et al*, in prep.) preliminary results show a considerable variability from place to place and year to year. In 1990 plastic represented approximately 47%, in 1991 33% and in 1992 30%, attributed mostly to measures favouring plastic substitution to paper which subsequently increased from approximately 14% in 1990, to 16% in 1991 and 23% in 1992. Metal ranged widely between 15 and 28%, glass from 6 to 10% and wood from 5 to 8%.

ii) Collection and measurement of floating litter was conducted by MARINO *et al* (1989) off the northern Spanish coast and by SAYDAM *et al* (1985) in the northeastern

Mediterranean. MARINO reported a mean concentration of 867 pieces / km^2 various plastic items, 522 pieces / km^2 styrofoam and 23.3 kg / km^2 of wood, whereas SAYDAM reports only 7.2 kg / km^2 total litter concentration.

iii) Apparently only one systematic study on sea-bed litter in the Mediterranean has been carried out by BINGEL *et al* (1987, 1989) on the Turkish continental shelf. Their work indicated a general trend of increase in litter density with depth. The mean concentration found is 28.63 kg km^2. Extrapolating this value to the whole of the Mediterranean continental shelf a figure of 16,000 tons is obtained.

Effects on Biota:

Plastics loose their volatile components in the sea water which also contributes to chemical pollution. However, the main effects marine litter has on the biota are damage to fish, marine mammals and birds through entanglement and ingestion. It has been stated that 30% of all fish taken from the N. Atlantic and the Mediterranean have swallowed plastics (HORSMAN, 1989). Likewise nylon threads have been found in the ovaries of groupers belonging to the genus *Epinephelus* off the east Tunisian coast (ANON., 1981).

There is more information about the harmful effect of litter on loggerhead turtles. GRAMENTZ (1988), examined loggerhead turtles (*Caretta caretta*), fished off Malta and he found that 20% of them were affected by oil, plastic and metal. During limited periods of captivity 8% of a sample of 91 speciments inadvertently captured in fishing nets, showed evidence of having previously swallowed plastic fragments. Plastic bags have been recovered in the digestive tracts of 4 out of 7 species of marine turtles inhabiting French coastal waters (IOC, 1988). In fact only transparent or milky plastic sheets were found in their intestines implying that turtles mistekenly take plastics for jellyfish and try to feed on them.

Finally marine litter cause damage to free navigation through entanglement in ship propellers and clogging intakes of cooling water systems. Aesthetic damage is caused to beaches and tourism, which is of high economic importance for the Mediterranean.

MICROBIAL POLLUTION

The microbial pollution of the Mediterranean sea has given rise to public concern. This is mostly due to the fact that in this region, much of the untreated sewage is still being discharged into the sea, untreated, and in a number of cases, through outlets which discharge directly on the coastline, rather than through a submarine outfall. Pathogenic bacteria, viruses, as well as unicellular algae and fungi pose a direct hazard to human health through one or more of the following routes: ingestion of contaminated seawater during swimming; skin contact with contaminated water or sand; and consumption of contaminated seafood. The situation has been reviewed by UNEP (1989) and more recently by AUBERT (1990) and SALIBA (1991). The situation shows that many areas, located near important towns, are subjected to microbiological contamination. However, bathing waters have generally improved in their environmental quality, mainly due to measures progressively being undertaken to control sewage discharges, together with increased monitoring of coastal waters. Nonetheless, it is generally felt that much further epidemiological evidence (especially on viruses and fungi) is required to be able to assess the microbiological quality of bathing waters and of seafood, in order to evaluate the hazards to man as well as the reliability of the control methods being developed.

The environmental quality of coastal waters may be affected by man not necessarily through the discharge of contaminants, but also through other activities such as dredging. CARRADA *et al*, (1991) have recently recorded the occurrence and abundance of the toxic, chain-forming dinoflagellate *Gymnodinium catenatum* in a Tyrrhenian coastal lagoon which is traditionally a shellfish farming area. While no shellfish intoxication has been yet reported, very high cell counts were recorded for this toxic species during late spring until early autumn. The authors suggest that intensive dredging in recent years with resuspension of bottom sediments may have seeded the water body with cysts.

CONCLUSIONS - RECOMMENDATIONS

The assessment of the pollution of the Mediterranean shows that despite already invested efforts and funds, the Mediterranean receives considerable pollution loads. The present results lead us to put more emphasis on the following facts :

The pollution from sewage, riverine and runoff inputs which was recognized in the past as the major one apparently is important, particularly for the so called "hot spots", but it is not the major one. The long distance atmospheric transport of pollutants mainly from Europe, is extremely important and for a number of substances the prevailing one.

Similarly the inputs from the Atlantic and the Black sea are also very important for some elements and sould be studied more thoroughly.

All inputs and particularly those entering the Mediterranean associated with liquid discharges have the tendency to be traped in a narrow nearshore zone mainly on the continental shelf, although in several cases there is evidence that through underwater canyons fine sediments and colloidals are transported under favourable hydrometeorological conditions, in fluxes, towards the open sea.

Strong evidence exists that deep sea Mediterranean sediments are affected by anthropogenic particles brought there also through the atmosphere.

These results raise a series of questions concerning the connection of the pollution generated with the very issue of sustainable development in the Mediterranean and in Europe.

One of the keys to address this problem is to speed up the clean production, the sustainable technologies (clean and other) and to balance the new approaches with the traditional end-of-the pipe abatement technologies.

I. Since most of the atmospheric inputs are closely connected with combustions and the latter is connected with CO_2 emissions and the climatic change, one could see that the introduction of the energy/CO_2 tax and the eventual decrease of the emissions with parallel promotion of energy saving as well as wind and solar energy could greatly help also to the reduction of the atmospheric pollution and the marine pollution connected with it.

II. Similarly, traditional well known approaches for the reduction of oil and liter from the ships by promoting modern, efficient port reception facilities and by stregthening the effective systems for prevention and management of risk, are always needed urgently in the Mediterranean.

III. Several of the pollution problems are directly or indirectly connected with the fresh water deficiency, in turn related to the destruction of plant cover and forest fires as well as with the works for "agressive" traffic, urban and touristic expansion. These closely interrelated themes need further study in a holistic way and promotion of new approaches aiming at the reduction of unsustainable modes of agriculture, reduction of mobility and minimisation of heavy infrastructures (highways, dams, etc.). In fact by integrating efficiently into the development policies the protection of the environment.

For a scientifically sound assessment of the evolution of the pollution in the Mediterranean and information of decision makers and the public opinion there is a need for monitoring based only on high quality, intercallibrated or by other way guaranted measurements.

Therefore :

1. There is need for a systematic, very selective, well organised programme of monitoring of aerosols, waters, particulate matter in the water column and sediments in a network of relatively few well chosen sites, placed in coastal waters and offshore thoughout the Mediterranean in order to collect reliable information about fluxes and concentrations of several crucial substances.

2. The currently on going monitoring projects which are run by national or regional authorities in the framework of UNEP/MAP need a thorough, critical revision by a Task Force of independent experts to be set up by UNEP/MAP in collaboration with other competent bodies.

Among other issues there is an urgent need to define the appropriate grain-size samples to be used in sediment analyses (most probably the pelitic or clay size fraction), the appropriate organs of mussels or other bioindicato than the total soft part of the mollusc) and the origin of them (most probably transplanted organisms rather than indigenous ones), or the use of suitable cosmopolitan green algae such as *Ulva sp.* (SCOULLOS and KABERI, 1991). For a more detailed discussion of the Biological Monitoring and its Applicabilities in the Mediterranean see the attached to the present paper Annex I (by V. Axiac).

3. A particular effort should be made so that the type of monitoring and data to be produced in the Mediterranean are compatible with the methodologies which are going to be adopted and/or developed by the EEA.

4. Research projects funded by EC, UNEP and other international organisations require further coordination and in fact the EC in particular should prepare a specific

list of formulated questions and research themes in the Mediterranean where the true scientific priorities - particularly for areas virtually unstudied- are recognised and promoted resisting traditional trends and pressures of strong political, scientific or other lobbies.

5. The effective exchange of scientific knowledge and expertise among scientists working in the area should be encouraged :

a) the CIESM biannual or triannual meetings should be strengthened and supported so that more scientists are supported to attend and present their research for the Mediterranean whereas the results should given the chance to be published in extenso.

b) meetings of sectorial and multidisciplinary scientific groups on specific issues should be organised more frequently,

c) exchange of researchers, experts and students to be supported.

6. The efficient and rapid interpretation of scientific findings and use of them for drafting of policies and proper development of public awareness. This requires :

(a) the strengthening of NGOs particularly those who have the ability to influence the Public Opinion but also the willingness to work in collaboration with Universities and other Learned Institutions.

b) a system for rapid collection and transmission of treated and raw data and other information which should be collected at a focal point (most probably UNEP/MAP) connected electronically to the EEA and eventually national focal points and/or cooperating institutes.

Adequate funds should be allocated for the development, training of personnel and proper maintenance and functioning of such a network. The same network could be combined with other existing ones and/or used for a number of other services eg. provision of bibliography legal or emergency advice to Goverments and other users. Some of them (companies, consultants, perhaps Universities, etc.) could be connected provided that they pay annual fees.

ANNEX I

Biological Monitoring and its Applicability in the Mediterranean

1 Bioaccumulation Indicator Species

Marine organisms may accumulate contaminants within their tissues. This phenomenon is not necessarily detrimental to the organism and may not always be equated with a stress condition. Bioaccumulator indicator species such as mussels have been used to monitor levels of contaminants in coastal waters in many regions including, the U.S.A (Mussel Watch Programme), Australia, Japan, South Africa and the Mediterranean. The range of contaminants analysed for include: trace and heavy metals, radionuclides, and organic pollutants such as organometals, and petroleum hydrocarbons. The aim of this monitoring was to protect human health by estimating exposure via consumption of seafood, as well as to protect valuable living resources. This method was particularly useful in identifying 'hot spots' or areas where levels of contaminants were particularly high, as well in identifying trends in coastal contamination. However, this is basically a chemical monitoring programme and in order to use such information for the purpose of environmental assessment, there is still the need to couple these chemical measurements with measurements of biological effects (FARRINGTON *et al*, 1987). At the regional level, environmental monitoring within the Mediterranean occurs within the framework of the MED POL-Phase II programme of the Mediterranean Action Plan. A critical assessment of this programme has been made by JOANNY (1990). *Mytilus* spp (mussels) and *Mullus barbatus* (red mullet) have been used as bioaccumulation indicator species to monitor heavy metals, and organochlorines (eg. DDT, polychlorobiphenyls). The author concluded that the use of such bioaccumulator species,to date, while providing the most reliable data, could not identify significant differences in levels of marine contaminants in the different regions within the Mediterranean, nor could they identify 'hot spots'. On the other hand, at the national level, due to more standardized methodlogies, and a more rigorous data quality assurance programme, the French monitoring programme made successful use of such bioaccumulation species to identify 'hot spots' of marine contamination along the French Mediterranean coastline.

2 Bioassays

Much progress has been achieved over the past two decades in the development of a range of bioassays for use in biological monitoring. A bioassay utilizes the measurement of a biological effect to indicate the presence of one or a combination of stressors (chemical or otherwise). The biological effect may be studied at various levels of biological organisations including: the molecular level, the cell, the individual, the population or the community and ecosystem level. To be useful for the purpose of environmental management, such bioassays should be sensitive to the lowest levels of contaminants so as to ensure the earliest possible detection of harm; be responsive to a wide range of contaminant levels in a quantitative and predictable manner; be fast and cost-effectively easily measured; and must demonstrate a long-term negative impact on growth, reproduction or survival of the organisms. No single bioassay satisfies fully all such criteria, and therefore a biomonitoring programme often has to include a range of such bioassays.

The types of bioassays which are currently available and which have shown a proven potential for field monitoring are included in table 1. A wider range of bioassays are indeed available, but these are either of dubious specificity, sensitivity or ecological relevance or have not been sufficiently tested in the field.

TABLE 1: A comparative review of some bioassays and their potential for use in environmental monitoring programmes in the Mediterranean.

	Mixed Function Oxygenases	Methallo-thioneins	Cellular Changes	Genetic Changes	Scope for Diversity	Species Abundance
Organisms Used	Mostly fish	Mostly mussels	Various	Various	Mostly Bivalves	-
Specificity of Response	Organic pollutants	Heavy Metals	General	General	General	General
Sensitivity	Varies	High	Medium	Varies	High	High
Dose-Response Relationship	Good	Good	Low	Unknown	Good	Low
Ability to Monitor Recovery	Unknown	Unknown	Unknown	Unknown	Good	Good
Ecological Significance	Low	Medium	Medium	Unknown	High	High
Sampling Validity	High	High	Medium	Unknown	High	High
Quality Control and Assurance	High	High	Medium	Unknown	High	Varies
Time of Response	Hours	Hours-days	Days-months	Days-months	Days-months	Months
Costs	Moderate	Moderate	Low	Moderate	Moderate	Low/Medium
Relative Ease of Assay	Complex	Complex	Moderate	Moderate/ Complex	Labour Intensive	
Potential for Monitoring	High	High	Medium	Unknown	High	High

Mixed function oxygenase (MFO) is a multienzymatic system found in various marine organisms, which catalyzes natural compounds or organic pollutants (such as polycyclic hydrocarbons and pesticides) so that they may be easily excreted by the body.

The induction of this system may be considered as a specific biological response to the presence of such pollutants and has been successfully used in a number of pilot environmental monitoring programmes, within the Mediterranean (LAFAURIE *et al*, 1991), and elsewhere. It is generally applied to fish, though other organisms such as marine plants (*Posidonia oceanica*) have also be used.

Another equally pollutant-specific biochemical marker of pollution, is the induction of certain body metalloproteins (*methallothioneins*) on exposure to heavy metals. Within the Mediterranean, VIARENGO *et al.* (1982) have successfully tested this bioassay to monitor heavy metal pollution using mussels as bioindicator species, in La Spezia, Italy.

Elevated levels of organotins resulting from the use of certain antifouling paints on marine craft, have been recently reported in a number of Mediterranean localities (GABRIELIDES *et al, 1990).* Such pollutants may cause harm to inshore species (including economically important organisms such as oysters) at very low concentrations (HOWELLS *et al*, 1990). One powerful bioassay, which has not been included in table 1, and which is highly specific to organotins is the induction of imposex (the imposition of male genitalia on females) in certain marine biomonitoring of organotins, within certain localities in the Mediterranean (eg. AXIAK, VELLA and MICALLEF, in preparation).

Other stress syndromes which are more general in their response to contaminants, include those associated with alterations in biological functions at the cellular, genetic and physiological levels. One commonly used bioassay of **cellular change** is the stability of Iysosomes and cell volume of digestive gland cells in mussels (MOORE, 1988). This bioassay is sensitive to low levels of both organic pollutants and heavy metals. **Genetic changes** (chromosomal aberrations, sister chromatid exchange, DNA breaks) also provide a potential set of general bioassays, which however still need to be fully developed and assessed in field studies. The **Scope for Growth** bioassay, measures the bioenergetic responses of bivalves to exposure of organics as well as heavy metals (and natural stressors) so that the amount of energy available for growth and reproduction may be calculated. It has proved a reliable index of pollution in a number of pilot biomonitoring programmes carried out outside the Mediterranean, as recently reviewed by Widdows (1991). Within the Mediterranean, while this bioassay has been utilized in laboratory investigations (eg. AXIAK and GEORGE, 1987) it has not been as yet used for pollution monitoring in the field.

The bioassays reviewed so far, particularly MFO, methallothioneins and Scope for Growth, would be able to detect and possibly predict environmental harm at the earliest possible stage. On the other hand, bioassays based on changes in marine populations or communities (eg. **Species Abundance/Diversity)** on exposure to contaminants, are by their very nature, descriptive of harm and retrospective, but not predictive or anticipatory. They may how be useful in monitoring recovery of the marine environment from some major pollution incident, or after a set of regulatory measures on chronic pollution are brought into effect. To date, such bioassays have been generally used to document environrnental harm in several localities within the Mediterranean (FAO,UNEP, 1987). HALIM (1990) has recently recommended the use of the marine community associated with the marine grass meadows of *Posidonia oceanica* to document long-term ecosystem changes (deterioration or otherwise) in the Mediterranean coastal waters. Studies carried out in the North-West region have shown the importance and vulnerability of such communities to human activities.

This type of of bioassay, although labour intensive and time-consuming, should provide a basin-wide index of environmental quality, deterioration and/or recovery, if standardized methodologies would be developed and fully implemented by as many laboratories as possible. The presence of certain algae such as *Ulva* may also be used to identify potential sources of sewage contamination.

CONCLUSIONS AND RECOMMENDATIONS

Although the merits of integrating bioassays in environmental monitoring have been fully recognized during the past 10 years, most regional (including the MED POL monitoring programme) and national environmental monitoring programmes still rely heavily on chemical monitoring and the utilization of bioaccumulation indicator species, to assess the levels of contaminants rather than evaluate their biological effects. Within the Mediterranean, the French national monitoring programme appears to be in the most advanced stage to include biological monitoring techniques on a regular basis.

At this stage of bioassay development, it is possible to develop an effective biomonitoring programme, which would be integrated in the present chemical monitoring programme, and which would be based on the use of biochemical markers such as MFO, methallothioneins, and cellular changes. This conclusion has been confirmed by a Working Group on Biomonitoring in the Mediterranean and the Black Sea which has been recently established by the Mediterranean Action Plan, in order to formulate a pilot biomonitoring programme in the region (FOA, UNEP, EMCMCH, 1992). The success of this pilot project will initially depend on the political will and availability of adequate resources for its implementation.

The limitations and inadequacies of the present chemical monitoring programme as have been recently discussed by JOANNY (1990), include: insufficient data quality control, incomplete geographical coverage and insufficient implementation of the required standardized methodologies. The realization of such limitations, will be an essential prerequisite in optimizing the present monitoring strategies and in ensuring the effective integration of a biomonitoring component in such a programme. Ultimately, the success of any region-wide environmental monitoring programme will depend on its compatibility with on-going national monitoring programmes and on its ability to communicate effectively relevant information on the state of the environment to the decision makers and environmental authorities.

Most of the bioassays reviewed above require a significant level of technical sophistication and expertise. This is often lacking in many regional laboratories especially along the southern Mediterranean. This problem should be tackled in an imaginative manner so as not to commit the same mistakes as for the chemical monitoring programme. For example, the idea of developing sub-regional laboratories which will specialize in a limited range of monitoring techniques and which will offer their services to the sub-region, should be seriously considered. This may be a more cost-effective strategy rather than that of trying to upgrade the capabilities of all the laboratories concerned in all methods. This will also require a strong and centralized coordination and evaluation of information being generated by the various sub-regional centres. The cost-benefits of such a strategy may be sufficient to overcome the initial politically-sensitive issues of confidentiality of information regarding national environmental quality.

Finally, it is hoped that the introduction of biomonitoring within the Mediterranean, will lead to the sensible application of existing biomonitoring technologies and methods within the region, rather than simply the divertion of the limited resources available to do more research of an academic rather than applied nature.

The reliability and potential of biological indicators

by Victor AXIAK

Marine Ectoxicology Laboratory, University of Malta, Msida, Malta

1. The Role of Environmental Monitoring in Strategies for Environmental Protection.

A management strategy for the protection of the marine environment should aim to protect the marine environment against the adverse effects of human activities so as to conserve marine ecosystems and to safeguard human health while providing for rational use of living and non-living resources (GESAMP, 1991). Such a strategy must necessarily be based on scientific information on the 'state of health' of the marine environment; on whether such state of health is improving or otherwise; and on whether any control measures being applied within the framework of this strategy, are being effective. Such scientific information is obtained through monitoring of the environment. More specifically, we need to accurately assess environmental quality through monitoring, in order to:

a) ensure cost-effective pollution control measures which are neither over- nor under-protective, as well as to optimize such control measures:

b) identify liabilities of potential polluters, as well as whether marine users are complying with regulations;

c) predict any consequences of man's activities on the marine environment at the earliest possible stage of planning of the activity.

However, there are certain basic problems which often prevent the scientific community from providing the necessary information on which a realistic environmental assessment may be based. These include: the complex nature of the marine environment and of its interactions with the atmosphere and with the landmass; the multidisciplinary and multifacet nature of the environmental issues often being discussed; the constantly changing technology and sources of pollution as well as the means and technology available for environmental monitoring.

These difficulties to provide the necessary environmental information through effective monitoring eventually led to the proposal that pollution problems may be solved by applying the" best available technology" concept (GESAMP, 1991). This aims at utilizing the best technology available to reduce marine contamination at point sources and to discourage the authorization of emissions when these are based on uncertain estimates of effects on the marine environment. If the best practical technology is available for waste treatment, then there was no need for any further environmental monitoring. Since then, experience has shown that such a strategy was not cost-effective and the role of environmental monitoring has been well established. It is wise to assume that whatever technological developments may be in store for the next century, it is inevitable that some marine contaminants will continue to be produced. These contaminants may indeed include chemicals which are as yet not recognized as being potentially harmful to man or to marine communities.

2. Approaches to Environmental Monitoring

Possibly, human activities are nowhere so intense in the world, as on the Mediterranean coastline. This is basically due to the relatively high coastal resident population densities as well as on the phenomenon of 'mass tourism' which is one of the basic features of local and regional economic developments. There is clear evidence that such human activities have exerted an overall negative impact on the integrity of the marine environment. The release of marine contaminants and of potential toxic substances from point sources or from diffuse coastal origins, may be considered as only one aspect of this negative impact. Any marine environment protection strategy must take into full consideration and in an integrative manner, all forms of impact, besides marine contamination. Indeed, environmental monitoring should ultimately aim at detecting and assess any detrimental change in the marine environment which may be caused by any of man's activities and not just by marine contamination or pollution.

This implies that any monitoring programme which provides only for chemical information on the levels of contaminants (often only of a limited range of suspected contaminants), is unable to achieve one of the most basic objective of such monitoring: namely to assess the 'state of health' of the marine environment, ie: to what degree organisms are being stressed by the presence of any (known, suspected or unsuspected) contaminant or any other anthropogenic insult. This may only be achieved through biological monitoring, that is, the assessment of environmental quality on the basis of the organisms' response to pollution or to other insult. Ultimately, both biological and chemical evidence are required to assess risks to the marine ecosystems effectively. Any cost-effective environmental monitoring programme must integrate a wide range of chemical and biological monitoring techniques, thereby avoiding replication and providing the sufficient scientific information required to predict the risk of damage to living resources or to man.

3. Biological Monitoring and it Applicability in the Mediterranean

3.1 Bioaccumulation Indicator Species

Marine organisms may accumulate contaminants within their tissues. This phenomenon is not necessarily detrimental to the organism and may not always be equated with a stress condition. Bioaccumulator indicator species such as mussels have been used to monitor levels of contaminants in coastal waters in many regions including, the U.S.A (Mussel Watch Programme), Australia, Japan, South Africa and the Mediterranean. The range of contaminants analysed for include: trace and heavy metals, radionuclides, and organic pollutants such as organometals, and petroleum hydrocarbons. The aim of this monitoring was to protect human health by estimating exposure via consumption of seafood, as well as to protect valuable living resources. This method was particularly useful in identifying 'hot spots' or areas where levels of contaminants were particularly high, as well in identifying trends in coastal contamination. However, this is basically a chemical monitoring programme and in order to use such information for the purpose of environmental assessment, there is still the need to couple these chemical measurements with measurements of biological effects (FARRINGTON *et al.*, 1987). At the regional level, environmental monitoring within the Mediterranean occurs within the framework of the MED POL-

Phase II programme of the Mediterranean Action Plan. A critical assessment of this programme has been made by JOANNY (1990). Mytilus spp (mussels) and Mullus barbatus (red mullet) have been used as bioaccumulation indicator species to monitor heavy metals, and organochlorines (eg. DDT, polychlorobiphenyls). The author concluded that the use of such bioaccumulator species,to date, while providing the most reliable data, could not identify significant differences in levels of marine contaminants in the different regions within the Mediterranean, nor could they identify 'hot spots'. On the other hand, at the national level, due to more standardized methodlogies, and a more rigorous data quality assurance programme, the French monitoring programme made successful use of such bioaccumulation species to identify 'hot spots' of marine contamination along the French Mediterranean coastline.

3.2 Bioassays

Much progress has been achieved over the past two decades in the development of a range of bioassays for use in biological monitoring. A bioassay utilizes the measurement of a biological effect to indicate the presence of one or a combination of stressors (chemical or otherwise). The biological effect may be studied at various levels of biological organisations including: the molecular level, the cell, the individual, the population or the community and ecosystem level. To be useful for the purpose of environmental management, such bioassays should be sensitive to the lowest levels of contaminants so as to ensure the earliest possible detection of harm; be responsive to a wide range of contaminant levels in a quantitative and predictable manner; be fast and cost-effectively easily measured; and must demonstrate a long-term negative impact on growth, reproduction or survival of the organisms. No single bioassay satisfies fully all such criteria, and therefore a biomonitoring programme often has to include a range of such bioassays.

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4. Conclusions and Recommendations

Although the merits of integrating bioassays in environmental monitoring have been fully recognized during the past 10 years, most regional (including the MED POL monitoring programme) and national environmental monitoring programmes still rely heavily on chemical monitoring and the utilization of bioaccumulation indicator species, to assess the levels of contaminants rather than evaluate their biological effects. Within the Mediterranean, the French national monitoring programme appears to be in the most advanced stage to include biological monitoring techniques on a regular basis.

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Etat actuel de la biodiversité marine en Méditerranée

par Charles-François BOUDOURESQUE

LBMEB, Faculté des Sciences de Luminy, 13288 Marseille Cédex 9, France

La biodiversité naturelle en Méditerranée

La biodiversité est très difficile à évaluer. En effet, si le nombre d'espèces décrites sur la terre est estimé à 1 393 000 (Wilson et Peters, 1988), tous les auteurs sont d'accord pour considérer que la très grande majorité des espèces n'ont pas encore été décrites. Le nombre réel d'espèces serait compris entre 5 et 100 millions (May, 1991, 1992 ; Chauvet et Olivier, 1993). D'une façon générale, au niveau spécifique, la biodiversité continentale est très largement supérieure à la biodiversité marine ; les barrières biogéographiques, l'insularité par exemple, y favorisent en effet les phénomènes de spéciation. En revanche, au niveau phylétique, la biodiversité marine est supérieure à la biodiversité continentale : de nombreux phylums sont en effet restés cantonnés au domaine marin.

En Méditerranée, Fredj et Maurin (1987) recensent près de 6700 espèces animales (à l'exclusion des Protozoaires). Quant à la flore, elle représente environ 1100 espèces (Tabl. I). En tenant compte des travaux postérieurs à ces évaluations, et des groupes systématiques qu'elles ne prennent pas en compte, le nombre d'espèces signalées en Méditerranée doit se situer autour de 10 000. Quoi qu'il en soit, la biodiversité de la Méditerranée, comme celle des autres mers et océans du globe, reste largement méconnue. Chaque année, plusieurs dizaines de nouvelles espèces sont signalées (ou décrites pour la première fois) en Méditerranée. En l'état actuel des connaissances, toute réflexion sur la biodiversité doit faire appel largement à des hypothèses. Il va de soi (même quand nous ne le précisons pas) que tous les chiffres qui figurent dans ce rapport ne constituent que des approximations.

La faune et la flore méditerranéennes sont **particulièrement riches**, et il ne semble pas qu'il s'agisse d'un artéfact lié à une pression d'étude plus importante que pour d'autres régions du monde. Chez les Fucophyceae (groupe presque exclusivement marin), par exemple, 18% des 1500 espèces décrites dans le monde (Bold et Wynne, 1978) sont présentes en Méditerranée, alors que cette mer ne représente que 0.8% de la surface de l'océan mondial. L'une des causes de cette richesse est sans doute la coexistence d'espèces de l'Atlantique tempéré et boréal, de l'Atlantique tropical et de l'Indo-Pacifique (Fredj, 1974). La répartition de cette biodiversité n'est pas homogène (Tabl. II) : 37% de la faune d'invertébrés (Fredj, 1974), 75% des poissons (Fredj et Maurin, 1987) et la quasi-totalité

Tableau I : Evaluation partielle du nombre d'espèces (ou de taxons) de la faune (d'après Fredj et Maurin, 1987 ; à l'exclusion des Protozoaires) et de la flore méditerranéennes (d'après Giaccone, 1974 ; Ribera *et al.*, 1992 ; Gallardo *et al.*, 1993 ; à l'exclusion des espèces pélagiques). * = espèces benthiques uniquement. ** = estimation.

Phylum	Nombre d'espèces
Porifera	622
Cnidaria	369
Echinodermata	144
Priapulida	3
Annelida*	791
Echiurida	6
Sipuncula	22
Brachiopoda	15
Entoprocta	19
Ectoprocta**	494
Mollusca**	1398
Arthropoda**	1938
Pogonophora	1
Phoronidea	4
Hemichordata	5
Chordata	198
Pisces	638
Cyanobacteria	165
Rhodophyta	465
Fucophyceae	265
Chlorophyta*	209
Phanerogama	6
TOTAL	7777

Tableau II : Répartition bathymétrique de la faune méditerranéenne () : nombre d'espèces observées en dessous d'une profondeur donnée, en pourcentage de la faune totale (d'après Fredj, 1974).

En dessous de (mètres)	Nombre d'espèces (en pourcentage)
0	100 %
50	63 %
100	44 %
150	37 %
200	31 %
300	25 %
500	18 %
1000	9 %
2000	3 %

de la flore algale sont cantonnés à la tranche bathymétrique 0-50 m ; pour ce qui concerne le benthos, cette tranche bathymétrique ne représente qu'environ 5% de la surface de la

Méditerranée. Inversement, moins de 9% de la faune méditerranéenne est présente en dessous de 1000 m de profondeur (Fredj, 1974).

La faune méditerranéenne présente **une forte similitude avec celle de l'Atlantique oriental** (côtes d'Europe et d'Afrique). Sur la base de 1244 espèces (Echinodermata, Priapulida, Polychaeta errantia, Echiurida, Sipunula, Brachiopoda, Mollusca, Crustacea Decapoda, Pogonophora, Phoronidea et Hemichordata), 66% de ces espèces sont communes avec la région lusitanienne, 50% avec la région mauritanienne ; en revanche, 18% seulement des espèces sont communes entre la Méditerranée et l'Indo-Pacifique (y compris les immigrants récents par le canal de Suez : immigrants lessepsiens) et 13% entre la Méditerranée et l'Atlantique occidental (côtes américaines) (Fredj, 1974). De même, le peuplement de poissons de la Méditerranée présente 64% d'espèces communes avec la région lusitanienne (Fredj et Maurin, 1987).

Tableau III : Nombre et pourcentage d'espèces (ou de taxons) endémiques pour un certain nombre de phylums de la faune méditerranéenne (d'après Fredj et Maurin, 1987, pour les poissons et Fredj, 1974, pour les autres groupes).

Phylum	Nombre d'espèces	Nombre d'endémiques	Pourcentage d'endémiques
Echinodermata	134	32	24 %
Priapulida	1	0	0 %
Polychaeta Errantia	371	88	24 %
Echiurida	6	1	17 %
Sipuncula	20	4	20 %
Brachiopoda	15	2	13 %
Mollusca	401	65	16 %
Crustacea Decapoda	286	52	18 %
Pogonophora	1	1	100 %
Phoronidea	4	0	0 %
Hemichordata	5	2	40 %
Poissons	638	117	18 %
Total	1882	364	19 %

La Méditerranée (et plus particulièrement la Méditerranée occidentale) apparaît comme **un foyer d'endémisme particulièrement actif**. Sur la base de 560 espèces d'Hydraires, Décapodes marcheurs, d'Echinodermes et d'Ascidies, Pérès et Picard (1964) évaluaient à plus de 29% le taux d'endémisme. Fredj (1974) le situe autour de 20% (Tabl. III), à partir des mêmes groupes qu'à l'alinéa précédent. Cette proportion varie selon les groupes systématiques : elle est par exemple plus forte chez les Echinodermes (24%) que chez les Mollusques (16% ; Fredj, 1974) ; elle est de 21% chez les algues (Giaccone, 1974). Le taux d'(endémisme varie également selon les secteurs : il atteint par exemple 26% pour les algues en Sicile (Giaccone et Geraci, 1989a). L'endémisme méditerranéen se manifeste beaucoup plus au niveau spécifique que générique ; il s'agit en effet d'un endémisme récent ou **néoendémisme**. Les crises messiniennes, au cours desquelles la Méditerranées s'est plus ou moins asséchée, avec disparition d'une grande partie de son peuplement, en sont sans doute la cause. A l'issue de ces crises, il y a environ 5 millions d'années, le peuplement de la Méditerranée a dû se reconstituer à partir de la faune et de la flore atlantiques. Le genre *Cystoseira* (Fucophyceae) illustre bien les phénomènes de spéciation qui se sont alors produits. Les espèces atlantiques, en pénétrant en Méditerranée, ont évolué, pour donner naissance successivement à plusieurs espèces échelonnées d'Ouest en Est et d'autant plus distinctes de la forme atlantique originelle qu'elles sont plus éloignées du détroit de Gibraltar (Sauvageau, 1912a, 1912b ; Feldmann, 1958).

La biodiversité de la Méditerranée occcidentale est supérieure à celle de la Méditerranée orientale : 51% plus forte pour les Fucophyceae (calculé d'après les données de Ribera *et al.*, 1992) et près de 100% plus forte pour la faune (Fredj, 1974). Le fait que l'effort de recherche ait été moindre en Méditerranée orientale ne peut expliquer à lui seul une telle différence. En Méditerranée orientale, la biodiversité est plus forte en mer Egée (Grèce et Turquie) que dans le Sud et le bassin levantin (Syrie, Liban, Israël, Egypte et Libye) (Tabl. IV).

Tableau IV : Nombre d'espèces (et pourcentage par rapport à l'ensemble de la Méditerranée) de Fucophycées dans les différents secteurs de Méditerranée. Nord-occidental = Espagne continentale, Baléares et France continentale ; Mer Tyrrhénienne = Italie occidentale, Corse, Sardaigne, Sicile ; Afrique du Nord = Maroc, Algérie et Tunisie ; Bassin levantin (inclus Sud de la Méditerranée orientale) = Syrie, Liban, Israël, Egypte et Libye (calculé d'après les données de Ribera *et al.*, 1992).

Secteur	Nombre d'espèces	Pourcentage
Nord-occidental	161	61%
Mer Tyrrhénienne	183	69%
Afrique du Nord	119	45%
Adriatique	160	60%
Mer Noire	80	30%
Grèce et Turquie (Méditerranée)	122	46%
Bassin levantin	74	28%

La diversité n'est pas seulement celle des espèces (biodiversité) mais aussi celle des écosystèmes (**écodiversité**) ; cette dernière est décrite dans des synthèses telles que celles de Pérès et Picard (1964) et Gamulin-Brida (1974). Dans le présent rapport, nous inclurons l'écodiversité dans la biodiversité, considérée au sens large.

L'érosion de la biodiversité méditerranéenne

Les activités humaines susceptibles de diminuer la biodiversité sont l'aménagement du littoral (avec recouvrement des fonds : ports, plages artificielles, endigages), la pêche (pêche professionnelle, chalutage, surexploitation et pêche amateur), la pollution (nutrients, matières organiques, métaux lourds, turbidité) et le dumping (rejets solides). Ces activités concernent principalement le plateau continental, et plus particulièrement l'étage infralittoral (0 à 30-40 m de profondeur), principal réservoir de la biodiversité. Elles sont très irrégulièrement réparties en Méditerranée ; la surface des fonds occupés par des aménagements littoraux est considérable en Catalogne (Folch i Guillèn, 1988), País valenciano (Vera Rebollo, 1991), Languedoc-Roussillon (France : Oliver, 1991), Provence-

Côte d'Azur (France ; Tabl. V) et Ligurie (Italie) ; les apports de polluants ont commencé à décroître le long des côtes françaises, où plus des 75% des eaux usées transitent par des stations d'épuration, alors qu'ils continuent à augmenter partout ailleurs.

Tableau V : Pourcentage de la surface des fonds infralittoraux occupés (et détruits de façon irréversible) par des aménagements (ports, plages artificielles, endigages) en région Provence-Alpes-Côte d'Azur (France). D'après Meinesz et Lefèvre (1978), Meinesz *et al.*, (1981) et Meinesz *et al.* (1982).

Tranche bathymétrique	Bouches du Rhône	Var	Alpes-Maritimes
0 - 10 m	25 %	10 %	18 %
0-20 m	18 %	6 %	12 %

Pour le moment, **aucune espèce ne semble avoir effectivement disparu** de Méditerranée. Quelques unes ont toutefois disparu de secteurs plus ou moins étendus et apparaissent **sont susceptibles de disparaitre dans un proche avenir**. C'est le cas du phoque moine *Monachus monachus*, autrefois répandu dans l'ensemble de la Méditerranée, et qui ne subsiste plus qu'en Grèce, Turquie, Algérie, Maroc (y compris les îles espagnoles des Chafarinas) et peut-être Libye et Albanie. Il s'agit selon le WWF de l'une des 10 espèces dans le monde les plus menacées de disparition. Au cours des 20 dernières années, ses effectifs totaux sont passés de 1000 à environ 300 individus, dont 150 à 170 pour la Méditerranée (Marchessaux, 1989a, 1989b ; Ramade, 1990). Les causes du déclin du phoque moine sont **(i)** la réduction de son habitat naturel (plages, grottes) face à l'aménagement et au tourisme (Oztürk, 1992), **(ii)** la surexploitation des stocks de poissons dont il se nourrit, qui conduit à la dispersion des individus et au parasitage des filets de pêcheurs (Boudouresque et Lefèvre, 1988), et **(iii)** sa destruction par les pêcheurs (Jacobs et Panou, 1988), destruction qui est une conséquence du point précédent. Un Mollusque, la patelle géante *Patella ferruginea*, est également en grand danger de disparition ; autrefois répandu tout autour de la Méditerranée occidentale, il ne subsiste plus qu'à l'état de populations très clairsemées en Corse, Sardaigne, Tunisie, Algérie et Sud de l'Espagne (Boudouresque et Laborel-Deguen, 1986 ; Laborel-Deguen et Laborel, 1990, 1991a, 1991b ; Porcheddu et Milella, 1991) ; son déclin s'est accéléré au cours des dernières années (J. Laborel, comm. pers.). La cause de la disparition de cette espèce de grande taille (parfois plus de 10 cm de diamètre), qui vit dans l'étage médiolittoral (c'est-à-dire un peu au dessus du niveau moyen de la mer), est le ramassage par l'homme, soit pour être consommée, soit pour servir d'appât de pêche.

Sans qu'elles semblent menacée de disparition dans un avenir immédiat, un certain nombre d'espèces apparaissent comme **vulnérables**. Ce sont soit des espèces dont les effectifs sont modestes, soit des espèces dont les stations sont très localisées, de telle sorte qu'elles sont à la merci d'un aménagement ou d'une pollution ponctuels, soit des espèces encore relativement communes mais dont les populations déclinent rapidement. Plusieurs **Livres rouges** en ont recensé une cinquantaine (Wells *et al.*, 1983 ; Baghdiguian *et al.*, 1987 ; Lacaze, 1987 ; Boudouresque, Ballesteros *et al.*, 1990). Il s'agit par exemple de la Chlorophyta *Penicillus capitatus*, du Mollusque *Pinna nobilis* (tout au moins, pour ce dernier, en Méditerranée nord-occidentale) et de la tortue marine *Caretta caretta* (couanne). Cette dernière a récemment déserté les sites de ponte du bassin occidental de la

Méditerranée ; les rares plages qu'elle fréquente encore pour y pondre sont situées en Méditerranée orientale : Lampedusa (Italie), Zakhintos (Grèce ; le site le plus important), Lara (Chypre), etc (Ramade, 1990).

Si aucune espèce ne semble, pour le moment, avoir totalement disparu de Méditerranée, il n'en est pas de même à l'échelle des régions. Dans la lagune de Venise, par exemple, où Schiffner et Vatova (1938) recensaient 141 espèces d'algues, Pignatti (1962) n'en observe que 104 et Sfriso (1987) plus que 95 (la pression d'observation étant du même ordre) ; le changement qualitatif est plus profond encore, puisque de nombreuses espèces ont disparu, remplacées par des espèces tolérantes à la pollution (Sfriso, 1987).

Certains écosystèmes ont régressé de façon spectaculaire au cours des denières décennies. C'est le cas de l'**herbier à *Posidonia oceanica*** (Boudouresque et Meinesz, 1982 ; Pérès, 1984 ; Mazzella *et al.*, 1986 ; Boudouresque, Ballesteros *et al.*, 1990). La régression se fait principalement autour des grands centres industrialo-portuaires (Barcelona, Marseille, Toulon, Nice, Genova, Napoli, Athènes, Alger, etc) ; elle se manifeste également à plus grande distance par une remontée de la limite inférieure (normalement située entre 30 et 40 m de profondeur) due à l'augmentation de la turbidité de l'eau et à la diminution consécutive de la quantité d'éclairement parvenant au fond (Meinesz et Laurent, 1982). L'herbier à *Posidonia oceanica* joue un rôle très important en Méditerranée : production de matière organique (à la base du réseau trophique), frayère et nurserie pour de nombreuses espèces (en particulier pour des poissons d'intérêt commercial), fixation des fonds meubles, atténuation des vagues et de la houle (protection des plages) ; sa régression est donc considérée comme ayant des conséquences économiques graves (Bellan-Santini et Picard, 1984 ; Jeudy de Grissac, 1984a). En outre, l'herbier à *P. oceanica* est (avec le coralligène) le principal **pôle de biodiversité** en Méditerranée. Parmi les autres écosystèmes dont la régression est préoccupante en Méditerranée, on peut citer les peuplements à *Cystoseira* (Fucophyceae) de mode battu, les peuplements à *Cystoseira* de profondeur, les peuplements à *Laminaria rodriguezii* (Fucophyceae), les peuplements à *Laminaria* du Sud de la Méditerranée occidentale (île d'Alboran, Alger et détroit de Messina) et les fonds coralligènes (Bellan-Santini, 1966 ; Fredj, 1972 ; Giaccone, 1972 ; Laborel, 1987 ; Boudouresque, Ballesteros *et al.*, 1990).

Certains **faciès ou paysages** particuliers sont également menacés. C'est le cas des **récifs-barrières** de l'herbier à *Posidonia oceanica*. Les baies abritées dans lesquelles ils sont localisés ont presque toutes été aménagées (ports) et les rares récifs-barrières qui subsistent sont aujourd'hui menacés par la navigation de plaisance (mouillages forains) (Augier et Boudouresque, 1970 ; Boudouresque *et al.*, 1985 ; Boudouresque, Ballesteros *et al.*, 1990). L'**herbier tigré** est un type très particulier d'herbier à *P. oceanica*, caractérisé par une disposition en bandes parallèles étroites ou en micro-atolls et localisé dans le golfe de Gabès (Tunisie) et en Sicile (Calvo et Frada-Orestano, 1984 ; Boudouresque, Ballesteros *et al.*, 1990) ; il est menacé par la pollution. L'**encorbellement construit par l'algue calcaire *Lithophyllum lichenoides*** (Rhodophyta), plus connu sous le nom de "trottoir", est très caractéristique de la Méditerranée occidentale. Il se développe dans l'étage médiolittoral, un peu au dessus du niveau moyen de la mer ; son édification nécessite plusieurs siècles (Laborel *et al.*, 1983 ; Ballesteros, 1984 ; Laborel, 1987). Très sensible à la pollution (les hydrocarbures principalement), il a en grande partie disparu de régions entières (Pyrénées-Orientale et Bouches-du-Rhône, France, par exemple). L'un des plus larges trottoirs de

Méditerranée, celui de Porquerolles (Var, France) semble inactif (J. Laborel, comm. pers.) ; quant à celui de Punta Palazzu (Scandola, Corse), le plus spectaculaire de Méditerranée, il est victime de sa notoriété : l'accostage des embarcations et le piétinement des visiteurs l'ont gravement endommagé (Boudouresque, Ballesteros *et al.*, 1990 ; J. Laborel, comm. pers.).

Dans le domaine continental, certaines activités humaines (agriculture traditionnelle, pâturage) déterminent des paysages que l'on souhaite conserver et ont contribuer à augmenter la biodiversité. Inversement, l'abandon des terres agricoles et **le retour vers un climax monotone** ont pour résultat une diminution de la biodiversité, avec élimination possible de certaines espèces rares. Un tel phénomène s'observe par exemple dans le Parc National de Port-Cros (Var, France). Ce problème ne semble pas concerner, pour le moment, le domaine marin. On remarque toutefois que, dans la Réserve Naturelle de Scandola (Corse), la protection a eu pour résultat une augmentation de la biodiversité des poissons (Francour, 1992), mais parallèlement ("effet cascade") une baisse de la biodiversité de la faune benthique dont se nourrissent les poissons (Boudouresque, Caltagirone *et al.*, 1992).

Introductions d'espèces et impact sur la biodiversité

Le **percement du canal de Suez** a été à l'origine d'un enrichissement considérable de la faune et de la flore méditerranéennes : environ 350 espèces sont en effet arrivées en Méditerranée à partir de la Mer Rouge (Por, 1990), ce qui représente environ 5 à 6% du peuplement de la Méditerranée (Fredj, 1974) ; pour les poissons, les immigrants lessepsiens représentent 7% du total des espèces méditerranéennes (Fredj et Maurin, 1987). La presque totalité de ces espèces son restées cantonnées à la Méditerranée orientale, que Por (1978, 1980) désigne sous le nom de "Province lessepsienne". L'entrée en Méditerranée d'espèces de Mer Rouge se poursuit actuellement ; elle est facilitée par la faible biodiversité de la Méditerranée orientale. Ces espèces réoccupent une région qu'elles ont sans doute colonisée dans le passé, et d'où elles ont été exclues par les crises qu'a subies la Méditerranée (assèchement partiel lors des crises messiniennes, refroidissement lors des époques glaciaires, crises anoxiques en profondeur). Il serait très difficile d'arrêter ou de ralentir ce phénomène (par exemple par la mise en place d'écluses dans le canal de Suez), phénomène qui de toutes façons ne semble pas préoccupant.

D'autres causes d'introduction ont permis à un grand nombre d'espèces de s'installer en Méditerranée. La principale est l'**aquaculture** ; introduction délibérée d'espèces d'intérêt économique, comme la crevette *Penaeus japonicus*, ou espèces introduites accidentellement avec les espèces d'intérêt économique ; l'importation de naissain de l'huître japonaise *Crassostrea gigas* a eu pour conséquence l'introduction en Méditerranée de nombreuses espèces d'algues telles que *Laminaria japonica*, *Undaria pinnatifida*, *Sargassum muticum*, *Chrysymenia wrightii*, et *Antithamnion nipponicum* (Pérez *et al.*, 1981 ; Ben Maiz *et al.*, 1987 ; Verlaque, 1989 ; Verlaque et Riouall, 1989 ; Belsher, 1991). De nombreuses espèces ont également introduites avec le **fouling** (organismes se fixant sur des substrats artificiels, coques des navires en particulier) ; c'est le cas du Bryozoaire *Tricellaria inopinata* dans la lagune de Venise (Occhipinti Ambroggi, 1991) et du Scléractiniaire *Oculina patagonica* dans des ports d'Italie et d'Espagne (Zibrowius, 1974 ; Zibrowius et

Ramos, 1983). Les **appâts pour la pêche** seraient à l'origine de l'introduction de *Fucus spiralis* (Fucophyceae) dans un étang languedocien (Sancholle, 1988). Enfin, le développement de l'**aquariologie**, qui est à l'origine de très nombreuses introductions dans les eaux douces (Welkomme, 1992), est responsable de l'introduction de l'algue verte tropicale *Caulerpa taxifolia* en Méditerranée (Meinesz et Hesse, 1991).

Au total, une trentaine d'espèces d'algues (María Ribera, comm. pers.) et une cinquantaine d'espèces d'invertébrés (Zibrowius, 1991) ont été introduites en Méditerranée autrement que par le canal de Suez. Les milieux où s'est effectuée l'acclimatation initiale sont le plus souvent des biotopes à faible biodiversité : lagunes littorales, ports, sites pollués. On peut donc considérer, en première approche, que les introductions d'espèces aboutissent à **une augmentation de la biodiversité**. En fait, certaines espèces introduites entrent en **concurrence** avec les espèces indigènes. Dans l'étang de Thau (Méditerranée, France), la sargasse géante *Sargassum muticum* (Fucophyceae) a éliminé l'algue indigène *Cystoseira barbata* de certaines stations, ainsi que son cortège floristique : la diversité (indice de Shannon) est exceptionnellement faible dans les peuplements à *S. muticum* (Gerbal *et al.*, 1985). De même, sur la côte d'Azur, le Recouvrement des algues indigènes est 500 fois plus faible dans les peuplements à *Caulerpa taxifolia* que dans les peuplements d'algues photophiles qu'ils remplacent (Boudouresque *et al.*, 1991 ; Boudouresque et Gomez-Garreta, 1992) ; en outre, *C. taxifolia* est capable d'éliminer, en quelques années, les herbiers à *Posidonia oceanica*, tout au moins à moins lorsqu'ils ne sont pas très denses et qu'ils sont situés à moins de 20 m de profondeur (Boudouresque, Bellan-Santini *et al.*, 1992). En Méditerranée orientale, la crevette Penaeidae *Penaeus japonicus* a remplacé plus ou moins complètement, selon les régions, l'espèce indigène *P. kerathurus* (Spanier et Galil, 1991).

Les priorités et opportunités d'intervention européenne

(1) Recherche :

- **(i) Inventaire de la biodiversité.** Alors que les études de systématique (description et reconnaissance des espèces) sont souvent considérées comme "dépassées", et que le nombre de systématiciens décline dans plusieurs pays d'Europe, il apparaît que le simple inventaire des espèces présentes est très loin d'être réalisé. Il en résulte que les programmes sur la biodiversité et sa conservation butent sur cet obstacle majeur ; des espèces peuvent disparaître avant d'avoir été décrites (Chauvet et Olivier, 1993). L'inventaire des espèces méditerranéennes doit donc être mené activement, en particulier dans les régions où l'effort de recherche a été peu important (Albanie, Algérie; Libye, côte Nord du Maroc). Une banque de données telle que MEDIFAUNE (Fredj, 1973, 1974) constitue un outil précieux pour recevoir les informations collectées.

- **(ii) Statut des espèces menacées.** Les espèces rares et les espèces supposées menacées doivent faire l'objet d'une évaluation précise de leur statut (effectfs, répartition) et de l'évolution de leurs effectifs dans le temps. On ne dispose en effet d'aucune donnée concernant la quasi-totalité de ces espèces. Une cinétique de déclin rapide, même lorsque une espèce ne semble pas menacée de disparition à court terme, constitue un signal d'alarme et doit conduire à mettre en oeuvre des actions volontaristes de conservation (statut de protection légale, protection des espaces où elle subsiste).

- **(iii) Impact économique de la protection des espaces littoraux.** On considère de plus en plus que la qualité des milieux littoraux, qui résulte de leur protection ou des actions d'assainissement des eaux usées, représente une forte valeur ajoutée pour le tourisme d'une part, la pêche professionnelle d'autre part (voir plus bas). Les peuplement coralligènes, les tombants couverts de gorgones, les grottes sous-marines, les mérous *Epinephelus guaza*, entre autres, constituent des attractions fortes pour une activité en très forte croissance, la plongée sous-marine récréative. Les données qui supportent ces considérations sont toutefois encore trop rares (Boudouresque, 1989 ; Bachet, 1992 ; de Groot, 1992 ; Ribera-Siguan, 1992).

- **(iv) Mise au point de techniques de quarantaine efficaces**, afin d'éviter ou de limiter les introductions accidentelles d'espèces (voir plus bas). Les pratiques existantes sont très empiriques : par exemple, le passage du naissain de l'huître japonaise *Crassostrea gigas* pendant 1 heure dans l'eau douce, théoriquement pratiqué en France.

- **(v) Impact des espèces introduites sur la biodiversité** (y compris l'écodiversité). Très peu de données existent dans ce domaine. On suppose (sans preuve) que les espèces de petite taille et peu abondantes on peu d'effets. On suppose que des espèces dominantes et de grande taille ont un impact plus important. Quant à l'effet de synergie entre les diverses espèces introduites qui peuvent coexister dans un même biotope, il n'a jamais été envisagé, tout au moins en Europe.

- **(vi) Techniques de restauration.** La mise en place de stations d'épuration et l'amélioration de la qualité des eaux dans certains secteurs du littoral rendent nécessaire l'élaboration de techniques destinées à accélérer la réhabilitation des secteurs concernés. La **réimplantation** de Phanérogames marines (*Posidonia oceanica* principalement) en est actuellement au stade expérimental (Meinesz et Verlaque, 1979 ; Cinelli, 1980 ; Cooper, 1982 ; Jeudy de Grissac, 1984b ; Meinesz *et al.*, 1990). Pour le moment, il n'existe pas d'herbier replanté comparable aux forêts issues du reboisement, dans le domaine continental. Les expériences doivent se poursuivre. Des **récifs artificiels** sont immergés le long des côtes de Méditerranée, pour améliorer la pêche professionnelle (Relini et Würtz, 1977 ; Riggio *et al.*, 1985 ; Charbonnel, 1990 ; etc) ; leur rôle dans la restauration de la biodiversité doit également être étudié. Enfin, la **réintroduction** (ou le **renforcement des populations**) doit être envisagée dans le cas d'espèces menacées ; une seule expérience a pour le moment été tentée en Méditerranée : elle concerne la réintroduction du mollusque *Patella ferruginea* dans le Parc National de Port-Cros (l'espèce a disparu des côtes continentales de France) à partir d'individus prélevés en Corse (Laborel-Deguen et Laborel, 1991c).

- **(vii) Mise au point d'indicateurs biologiques** de la qualité du milieu. Il s'agit d'espèces (ou d'ensembles d'espèces) qui, par leur présence (ou leur absence) témoignent de la qualité moyenne d'un milieu. Lorsque les espèces indicatrices sont benthiques (fixées sur le fond), elle intègrent en outre la qualité du milieu sur une période relativement longue. De tels indices, d'usage courant en milieu continental, sont encore rares en milieu marin (Bellan-Santini, 1966 ; Belsher, 1979). Ils sont supérieurs, ou complémentaires, par rapport aux mesures physico-chimiques dont l'usage est général mais dont l'interprétation (compte tenu de la très grande variabilité) est difficile, parfois impossible.

(2) Actions prioritaires : indépendemment des mesures générales destinées à améliorer la qualité des eaux littorales (et abordées dans un autre Rapport), les priorités sont les suivantes :

- (i) Protection légale de certaines espèces. Alors que plusieurs centaines d'espèces continentales sont protégées par la loi, leur nombre est dérisoire en milieu marin (Bigant, 1991 ; Pergent, 1991 ; Ribera Siguan, 1991) : *Posidonia oceanica, Cymodocea nodosa* (France, Catalogne, Valencia), *Zostera marina, Z. noltii* (Catalogne, Valencia), *Pinna nobilis* (Croatie, France), *Pinna pernula, Centrostephanus longispinus, Lithophaga lithophaga, Patella ferruginea, Scyllarides latus* (France), ainsi qu'un certain nombre de mammifères marins et de tortues marines (la plupart des pays). Des listes d'espèces à protéger existent ou sont à établir, pays par pays ou au niveau communautaire. Un certain nombre d'espèces nécessitent d'urgence un statut de protection légale (Tabl. VI).

Si la protection légale des espèces est nécessaire, elle n'est toutefois pas suffisante. Les mesures de protection légale doivent tout d'abord être **effectivement appliquées**, ce qui n'est pas le cas pour le phoque moine par exemple. Elles doivent en outre être accompagnées par des mesures de **sauvegarde des habitats naturels** des espèces protégées (Ramade, 1990) : Réserves naturelles (voir plus loin point **iii**), limitation de l'aménagement et de l'urbanisation du littoral (voir plus bas point **v**) ; c'est le cas par exemple de la protection des plages où vient pondre la tortue *Caretta caretta*. Enfin, des dédommagements financiers, pour des catégories socio-professionnelles (pêcheurs dans le cas du phoque moine) ou des collectivités territoriales (dans le cas des aires de ponte des tortues marines) doivent être prévues.

- (ii) Protection de peuplements et de paysages. Les peuplements ou les paysages qui doivent être protégés en priorité, en particulier dans le cadre de la conservation de l'écodiversité (Boudouresque, Ballesteros *et al.*, 1990) ou parcequ'ils constituent des réservoirs de diversité, figurent dans le Tabl. VII.

- (iii) Protection d'espaces remarquables. Les Réserves marines (le terme est ici pris au sens large) sont très peu nombreuses en Méditerranée (Meinesz *et al.*, 1983 ; Jeudy de Grissac et Ben Mustapha, 1986 ; Giaccone et Geraci, 1989a ; Ribera Siguan, 1989 ; Ramade, 1990 ; etc) et couvrent des **surfaces insignifiantes** : moins de 1000 ha en Italie, moins de 2000 ha en Espagne, moins de 10 000 ha en France (Ramade, 1990) ; il est à noter que ces chiffres regroupent des zones à protection renforcée, où la pêche est interdite (quelques centaines d'hectares seulement) et des zones à niveau de protection beaucoup plus limité. Au total, moins de 1/10 000° des fonds situés entre 0 et 20 m bénéficient, en Méditerranée, d'un statut de protection. Par ailleurs, les Réserves qui existent sont souvent des "Paper Parks", c'est-à-dire des espaces légalement protégés où la protection n'est pas effective (niveau de protection insuffisant, ou absence de responsable administratif et/ou de moyens matériels et humains pour assurer la protection). Les Réserves marines constituent un soutien indispensable à la politique de protection de la biodiversité (voir plus haut, point **i**) et de l'écodiversité (voir plus haut point **ii**). La politique de création d'espaces protégés

Tableau VI : Espèces menacées nécessitant impérativement un statut de protection légale (en partie d'après Jeudy de Grissac *et al.*, 1989 ; Boudouresque, Ballesteros *et al.*, 1990). Sauf indication contraire, il s'agit de l'interdiction de récolte, de transport, de détention et de commercialisation. Distribution géographique : RR = très rare, R = rare, AC = assez commun, C = commun, ? = présence à confirmer, > = populations en déclin rapide. Régions concernées par les mesures de protection demandées : CEE = Communauté économique européenne, E = Espagne, F = France, I = Italie, GR = Grèce.

Phylum Espèce	Distribution géographique Espagne	 France	 Italie	 Grèce	 Méd. occ.	 Méd. or.	 Hors Méd.	Protection demandée (région, type)
Rhodophyta								
Goniolithon byssoides		RR	RR	?	RR	?		CEE
Lithophyllum lichenoides	R	C>	AC>	RR	R	RR	R	GR
Ptilophora mediterranea				R				CEE ou GR
Schimmelmannia ornata			RR			RR	RR	CEE ou I
Fucophyceae								
Cystoseira sedoides			RR		R			CEE ou I
Laminaria ochroleura	RR		RR		RR		C	CEE
Laminaria rodriguezii	R	RR	R		R			F
Chlorophyta								
Caulerpa ollivieri	RR	RR	?			RR	RR	CEE
Penicillus capitatus (1)		RR	RR				AC	CEE
Phanerogama								
Posidonia oceanica	C>	C>	C>	C>	C>	R		CEE (2,3)
Cymodocea nodosa	C>	AC	C	C	C	C	R	(2,3)
Zostera marina	R	R	R	RR	RR	RR	AC	CEE (3)
Zostera noltii	R	R	R	R	R	R	AC	(3)
Echinodermata								
Centrostephanus longispinus	R	RR	R	AC	R	AC	AC	(2)
Mollusca								
Lithophaga lithophaga	AC	AC	AC	AC	AC	AC	AC	(2,4)
Patella ferruginea	R	RR>	RR>			RR		CEE (2)
Patella nigra	RR		?			RR	R	CEE ou E
Pinna nobilis	R>	RR>	R>	AC	R	AC		E et I (2)
Pinna pernula	AC	AC	AC	AC	AC	AC		(2)
Crustacea								
Scyllarides latus	R	RR	RR	R	AC	AC	R	I (2)
Pisces								
Epinephelus guaza	R	RR	RR	R	AC	R	R	F et IT (5)
Umbrina cirrosa	R	RR	RR	R	R	R		I (5)
Sciaena umbra	RR	R	R	AC	AC	AC	AC	F et I (6)

(1) Stade Penicillus uniquement.
(2) L'espèce est déjà protégée en France.
(3) L'espèce est déjà protégée en Catalogne et en País valenciano (Espagne).
(4) L'espèce est déjà protégée en Italie.
(5) La protection recommandée se limite à l'interdiction de la chasse sous-marine.
(6) La protection recommandée se limite à la fixation d'une taille minimale de capture : 30 cm de longueur totale.

Tableau VII : Les peuplements et paysages sous-marins de Méditerranée dont la préservation est nécessaire pour la conservation de l'écodiversité et de la biodiversité. (en partie d'après Jeudy de Grissac *et al.*, 1989 ; Boudouresque, Ballesteros *et al.*, 1990).

Distribution géographique : E = Espagne, F = France, I = Italie, GR = Grèce, W = autres régions de Méditerranée occidentale, Mo = autres égions de Méditerranée orientale, H = hors de Méditerranée ; + = présence.

Intérêt écologique : B = biodiversité (faune et/ou flore très originales), E = pôle d'endémisme. EC = écodiversité (peuplement rare, ou devenu rare), I = Importance pour d'autres peuplements (exportation de matière, alimentation des oiseaux, etc), IR = la destruction est irréversible (la reconstitution demande des siècles ou des millénaires), PR = forte productivité, R = important réservoir de biodiversité (faune et flore très riche).

Intérêt économique : A = Aquaculture, F = frayère et/ou nursery pour des espèces d'intérêt économique, L = contrôle de la staabilité des lignes de rivage (plages), P = pêche, T = tourisme (plongée sous-marine).

Peuplement ou paysage	Distribution géographique E	F	I	GR	W	Mo	H	Intérêt écologique	Intérêt économique
Lagunes littorales	+	+	+	+	+	+	+	I PR	P A
Encorbellements à Lithophyllum	+	+	+	+		+		B IR EC	
Trottoirs à vermets		+	+	+	+	+	+	EC	
Forêts à Cystoseira mode battu	+	+	+	+	+	+	+	EC	
Forêt à Cystoseira mode calme	+	+	+	+	+	+		R PR	
Herbier à Posidonia oceanica	+	+	+	+	+	+		E R I IR PR	F P L
Récif-barrière de Posidonies	+	+	+		+	+		EC IR	
Herbier tigré de Posidonies			+		+	+		EC IR	P
Herbier à Zostera marina	+	+	+	+		+	+	EC	
Grottes sous-marines	+	+	+	+	+	+	+	EC B	T
Coralligène	+	+	+	+	+	+		R E	T P
Maërl	+	+			+		+	EC	

reste largement velléitaire en Méditerranée et doit être considérablement accélérée. Les espaces dont la protection est urgente pour assurer la conservation de la biodiversité et/ou de l'écodiversité figurent dans le Tabl. VIII.

- (iv) **Protection d'espaces destinés au repeuplement des zones périphériques en espèces exploitées.** Beaucoup de poissons littoraux changent de sexe au cours de leur vie : ils sont femelles lorsqu'ils sont jeunes puis mâles, ou le contraire. Il en résulte que les populations surexploitées, d'où les individus de grande taille sont absents, sont déficitaires en l'un des deux sexes. En outre, la reproduction sexuée est souvent un phénomène collectif, avec des pariades mettant en jeu de nombreux individus d'âge varié. L'interdiction de la pêche dans un secteur permet aux espèces marines (poissons en particulier) de se reproduire. Il est vérifié qu'une réserve contribue à repeupler les zones périphériques (Bell, 1992 ; Ramos, 1992), et ainsi à augmenter les tonnages qui y sont pêchés. Les pêcheurs professionnels sont donc les bénéficiaires des mesures de protection.

Tableau VIII : Les espaces dont la protection est nécessaire pour assurer le mainien de la biodiversité marine (y compris de l'écodiversité) en méditerranée (en partie d'après Jeudy de Grissac *et al.*, 1989 ; Lefèvre *et al.*, 1989 ; Ramade, 1990). Quelques sites hors CEE sont mentionnés lorsqu'ils constituent un élément de base dans une stratégie globale de protection. Mesures de protection spécifiques minimales pour que l'espace considéré remplisse sa mission : A = interdiction de tout aménagement littoral, CH = interdiction des chalutages, M50 = interdiction du mouillage forain des embarcations de plus de 50 m, N = interdiction de la navigation, PA = interdiction de la pêche amateur. POL = contrôle de la pollution, PP = interdication de la pêche professionnelle, QS = fixation de quotas de fréquentation pour la plongée en scaphandre..

Pays Site	Espèces, peuplements ou paysages dont la protection est plus particulièrement recherchée	Mesures de protection spécifiques
Espagne		
Cabo de Creus	Coralligène	PA, QS A
Cabo de Gata (1)	Monachus monachus (2)	PP PA
Banc d'Alboran	Laminaria ochroleuca	
France		
Archipel de Riou (Marseille)	Grottes sous-marines	PP PA QS
Lagune du Brusc (Var)	Récif-barrière Posidonies, Cymodocea	N POL A
Rade d'Hyères (Var)	Herbier de Posidonies, Pinna nobilis	POL M50 CH
Anse du Croton (Alpes-Ma.)	Caulerpa ollivieri	A
Saint-Florent (Corse)	Récif Posidonies	N POL A
Santa Manza (Corse)	Penicillus capitatus	A POL
Italie		
Marsala : Stagnone (Sicile)	Récif-barrière et erbier tigré Posidonies	A N POL
Taormina (Sicile)	Schimmelmannia ornata	A POL
Détroit de Messina (Sicile)	Laminaria ochroleuca	POL
La Madalena (Sardaigne)	Herbier de Posidonie, Patella ferruginea	PA POL A CH
Grèce		
	A compléter	
Tunisie		
Golfe de Gabès	Herbier tigré de Posidonies	POL
Algérie		
El Kala (1)	Monachus monachus (2)	PA A QS
Banc de Matifou	Laminaria ochroleuca	CH POL
Iles Habibas-Mersat Medakh	Patella ferruginea, Monachus monachus	PP PA A QS
Rachgoun - Ras Kela	Monachus monachus (2)	PA A QS

(1) La zone rerrestre est déjà protégée.
(2) L'espèce a été présente dans un passé récent et pourrait s'y réinstaller si les mesures de protection proposées étaient adoptées.

species" de l'ICES devrait avoir valeur légale (il ne s'agit actuellement que de recommandations). On prendra en compte le fait que les espèces, une fois introduites, ne connaissent pas les frontières administratives, et qu'une décision ne saurait se prendre à un niveau local ou même national. Des mesures de **quarantaine** très strictes doivent être appliquées aux espèces introduites délibérément afin d'éviter qu'elle s'accompagnent d'introductions **accidentelles**. Les transferts de produits aquacoles d'un bassin à l'autre, à l'intérieur d'un pays ou de la Communauté européenne, ne doivent pas prendre en compte les seuls risques de transfert de pathologies, mais aussi le risque de transfert d'organismes associés. Une législation sur le contrôle des **eaux de déballastage** des navires (du type de celle adoptée par les USA) doit être élaborée. Une législation sur le contrôle des produits vivants transportés (délibérément ou non) par les personnes arrivant aux frontières de la Communauté européenne doit être élaborée (une telle législation existe au Canada, en Australie, etc). Une législation sur les **aquariums** (publics ou privés) possédant des espèces exotiques susceptibles de s'en échapper doit être mise au point.

- (vii) Elaboration d'un code de bonne conduite pour les techniques de restauration. Si des techniques de restauration existent (et a fortiori si elles ne sont pas réellement au point ; voir plus haut), il convient d'éviter leur utilisation anarchique et abusive : réimplantations de *Posidonia oceanica* comme **alibi** à des destructions liées à de nouveaux aménagements, immersion de décombres rebaptisés "récifs artificiels", mise en place de récifs artificiels dans des sites non appropriés, etc. Le problème se pose très concrètement (en France) dans le cas de *Posidonia oceanica*, où des collectivités locales essaient de contourner la loi de protection de *P. oceanica* en proposant des réimpantations (au succès hypothétique) en compensation de destructions (bien réelles). Quelques principes pouvant constituer les bases d'un code de bonne conduite sont présentés ci-dessous

Réintroductions d'espèces : éléments pour un code de bonne conduite

La réintroduction d'espèces disparues d'une région, ou le renforcement des populations d'une espèce devenue rare dans une région, ne doivent pas servir d'alibi à des destructions dans le cadre de l'aménagement du littoral. Les propositions de réintroduction (ou de renforcement des populations) doivent donc impérativement répondre aux impératifs suivants :

(a) Le site **(et le biotope)** de réintroduction ont été autrefois occupés par l'espèce réintroduite.

(b) Les **causes** de la disparition de l'espèce à réintroduire ont cessé d'agir : pollution, surpêche, pression humaine, etc.

(c) La réintroduction ne se fait pas **à proximité d'une population survivante** importante (éviter de "réintroduire pour réintroduire")

(d) Les connaissances sur la **biologie** de l'espèce (dynamique des populations, biologie de la reproduction, etc) permettent de penser que la réintroduction a des chances de succès.

(e) La réintroduction ne peut pas se faire **en compensation de la destruction** d'une population de la même espèce. Pour éviter une telle dérive, il est décidé que, dans un rayon de 5 km autoutour d'une destruction délibérée (dans le cadre d'un aménagement du littoral), aucune réintroduction ne peut être réalisée pendant une période de 10 ans.

(f) Le prélèvement d'individus destinés à la réintroduction ne doit pas **mettre en péril** la population source.

(g) Les individus destinés à la réintroduction ou au renforcement doivent provenir d'une population **génétiquement identique** (ou proche) de celle qui a occupé la région où est projetée la réintroduction.

(h) Les techniques de réintroduction (ou de renforcement des populations) ne doivent pas constituer une **nuisance** pour les espèces ou les écosystèmes indigènes.

(3) Les systèmes de surveillance et de suivi. Un certain nombre de systèmes de surveillance de la qualité des eaux littorales existent dans les pays de la CEE. En France existent les réseaux suivants : le Réseau de surveillance de la qualité bactériologique des eaux de baignade (Anonyme, 1986) ; le RNO ou Réseau national d'observation, qui mesure depuis 1974 les paramètres généraux de qualité : température, salinité, nutrients, contaminants chimiques (Claisse, 1989) ; le REPHY ou Réseau phytoplanctonique, qui enregistre depuis 1984 les perturbations phytoplanctoniques, tout particulièrement les unicellulaires toxiques (Belin *et al.*, 1989) ; le REMI ou Réseau microbiologique, qui surveille, depuis 1989 la qualité bactériologique des coquillages (Miossec, 1992) et enfin le Réseau de Surveillance Posidonies (Boudouresque, Bertrandy *et al.*, 1990).

- **(i) Utilisation d'indicateurs biologiques** de la qualité des milieux pour la surveillance des milieux littoraux. Ces indices sont encore rares en milieu marin (voir plus haut). Curieusement, lorsqu'ils existent, ils restent peu utilisés par les administrations, alors qu'ils sont dans certains cas plus efficaces et moins chers, et dans tous les cas complémentaires des paramètres physiques ou chimiques généralement suivis.

- **(ii) Extension du Réseau de Surveillance Posidonies** à l'ensemble de la façade méditerranéenne de la Communauté européenne. Ce système de surveillance est en place depuis 9 ans en région Provence-Alpes-Côte d'Azur. Il est basé sur le balisage des limites inférieures de l'herbier à *Posidonia oceanica* et le suivi des herbiers superficiels au moyen de photographies aériennes complétées par des vérités-mer (Boudouresque, Bertrandy *et al.*, 1990 ; Sinnassamy *et al.*, 1991). Le pas de temps (retour sur les sites) est de 3 ans. Les résultats sont maintenant concluants (Charbonnel *et al.*, 1992). Une première tentative d'extension de ce réseau de surveillance a eu lieu dans le cadre du programme CEE COST 647.

Conclusions

La biodiversité marine de la Méditerranée est **encore mal connue**. Les conclusions que nous dégageons doivent donc être considérées avec prudence. En l'état actuel des connaissances, **il ne semble pas que des espèces aient disparu** du fait de l'Homme. Au contraire, les activités humaines (aquaculture principalement) et le percement du canal de Suez ont abouti à l'introduction en Méditerranée de plus de 400 espèces.

Pourtant, de nombreuses espèces apparaissent comme **menacées**, soit en raison de leur **rareté** qui les rend vulnérables, soit en raison d'une cinétique de **déclin rapide**. Certaines d'entre elles sont même au bord de l'extinction. Le cas du **phoque moine** est particulièrement dramatique. Si le phoque moine venait à disparaître, et la cinétique du déclin de ses effectifs, laisse maintenant présager cette issue pour la première décennie du 21° siècle, les conséquences de cette disparition dépasseraient le cas particulier de cette espèce. Il s'avèrerait en effet que, à l'aube du 3° millénaire, l'Europe est incapable d'empécher la disparition d'une espèce spectaculaire, chez elle et à ses portes, malgré la sensibilisation du grand public, les moyens matériels mis en oeuvre et les moyens financiers dont elle dispose. Dans ces conditions, on voit mal quelle crédibilité pourrait conserver le discours protectionniste dans des régions du monde confrontées à bien d'autres problèmes (économiques, humains) que la disparition d'espèces animales !

Les menaces concernent également des **écosystèmes** (écodiversité), tels que l'herbier à *Posidonia oceanica* et le coralligène ; ces deux écosystèmes représentant les principaux pôles de biodiversité en Méditerranée, leur régression est en outre susceptible d'affecter plusieurs milliers d'espèces. Elles concernent plus particulièrement des faciès ou des paysages, encore plus fragiles, impossibles à restaurer car aboutissement de siècles ou de millénaires d'une lente évolution, tels que les récifs-barrière de *Posidonia oceanica* ou le trottoir à algues calcaires.

Il y a **urgence** a évaluer le **statut réel** de nombreuses espèces méditerranéennes : quand une cinétique de déclin est trop avancée, il devient en effet difficile, voire impossible, de l'inverser ; or, certaines espèces sont peut-être au bord de l'extinction sans que nous en ayons conscience. Il y a urgence à évaluer l'**impact des espèces introduites** sur les espèces et les peuplements indigènes : l'augmentation de biodiversité qui paraît devoir en résulter peut n'être que momentanée ou apparente. Il y a urgence à se doter des **outils législatifs** susceptibles de protéger les espèces et les espaces, de ralentir le flot des introductions d'espèces qui menace de submerger les espèces indigènes, avant de **banaliser** les peuplements méditerranéens.

Les institutions et grands programmes en place répondent-ils à ces urgences ? Dans le domaine de la **pollution** (dont l'impact sur la biodiversité est important) et de son contrôle, sans doute. Encore faudrait-t-il prendre en charge les problèmes de pollution des **rives Sud et Est** de la Méditerranée, en n'oubliant pas que les courants brassent rapidement l'eau Méditerranéenne, alors que son renouvellement est très lent (de l'ordre du siècle). En revanche, les avancées sont excessivement lentes dans le domaine de la **préservation de la biodiversité** (espèces et écosystèmes) par la protection des espèces et des espaces ; à l'exception de l'Espagne (qui a créé récemment plusieurs espaces protégés) et de la France (qui vient de protéger 6 espèces marines), peu de progrès ont été accomplis depuis 10 ans. La récente Directive Habitat de la CEE paraît très timide et son efficacité reste à démontrer. Enfin, la question des **introductions d'espèces** n'est absolument pas abordée. Il s'agit pourtant d'un phénomène qui, contrairement à d'autres, est encore en phase d'accélération ; ce sera peut-être l'un des grands problèmes écologiques du siècle à venir, et il ne pourra être règlé qu'au niveau international (communautaire en particulier).

Harmful algal blooms in the Mediterranean

by Marta ESTRADA

Institut de Ciències del Mar, Paseo Nacional, s/n08039 - Barcelona, Spain

1. Introduction

The phytoplankton consists of a variety of microscopic organisms which live in suspension in the water and provide the food basis for the living resources of fresh-water and marine ecosystems. Spring and autumn proliferations of phytoplankton are normal occurrences during the seasonal cycle in temperate marine environments. Apart of the seasonal blooms, generally due to diatoms (MARGALEF, 1985), accumulations of phytoplankton may occur when adequate nutrient supply coincides with high stability of the water column, an uncommon situation in the natural environment. Under these conditions, even organisms with relatively low growth rates can take advantage of certain water circulation patterns and reach high population densities at some spots. These biomass accumulations can be intense enough to give a colour, generally reddish brown, to the water, hence their name of red tides. Red tides are often due to dinoflagellates (a phytoplankton group, like the diatoms), but they may also be caused by other organisms. Most red tide producers are motile and many form resting cysts, which sink to the sediment and may play an important role as inoculum of future blooms. Although red tides may be naturally occurring phenomena in areas without anthropogenic influence (MARGALEF *et al.*, 1979), they are often considered as abnormal blooms and, in practice, these denominations are used as synonyms.

In some cases, but by no means always, phytoplankton blooms have adverse effects for the marine fauna and for human health. This has lead to the widespread use of the term "Harmful algal blooms". However, harmful effects of some organisms may occur with low population densities in the water or they may be due to non-dominant species present in relatively low concentrations.

2. Mechanisms of formation of red tides

The mechanisms leading to the formation of red tides are complex and there are many unexplained questions. In principle, high biomass can only accumulate when the time scale of phytoplankton growth is faster than the time scale of dispersion by flushing. As the growth rates of bloom organisms are not particularly high, the appearance of red tides is basically related to the persistence of adequate conditions during enough time (often red tides end up dispersed by a storm) and to the existence of mechanisms favouring active or passive accumulation of organisms (MARGALEF *et al.*, 1979). Concentration of motile or buoyant phytoplankton at the water surface may be favoured by downwelling circulation at fronts, thermal or wind driven convection patterns and transport of surface water towards the coast, due to the wind or to the general circulation (PINCEMIN, 1969; WYATT, 1975). Stability may be favoured by absence of winds, high temperatures and by the presence of a low salinity water layer influenced, for example, by freshwater runoff.

3. Algal blooms in Mediterranean coastal waters

Although the Mediterranean is, globally considered, an oligotrophic Sea, there are many offshore zones of high productivity, such as the Almeria-Oran front, associated with the upwelling generated by the Atlantic Current, and the Liguro-Provençal-Catalan front. In the coastal region, estuaries and lagoons present naturally high productivity. The same occurs in other semi-enclosed zones, such as commercial harbours. Many of these areas show signs of eutrophication due to high nutrient discharges from rivers and sewage outlets, and are often occupied by dense phytoplankton blooms. Typical examples of these environments are the bays of the Ebre Delta and the Albufera of Valencia, in Spain, the coastal lagoons of southeastern France, the lagoon of Tunis, the Kastela Bay in Croacia, and the Izmir Bay in Turkey (UNEP, 1989; UNEP/FAO, 1990; BARTH and FEGAN, 1990). A special mention must be made of the Adriatic Sea. Its shallow northern part, which receives a large nutrient load from the Po river, is repeteadly affected by large blooms of dinoflagellates and diatoms. On occasions massive quantities of mucilage are produced ("mare sporco"). JACQUES and SOURNIA (1978-79) provide a review of red tide phenomena recorded in the Mediterranean up to 1978. Early references are listed in FORTI (1906). The diatoms Skeletonema costatum, Nitzschia spp. and Thalassiosira spp. are some of the most frequently recorded as formers of particularly dense blooms (KORAY, 1990; MARCHETTI, 1992), although, as noted above, diatom proliferations are normal occurrences in the seasonal cycle. Among other groups of organisms, the chloromonad Chattonella subsalsa was responsible of water discolouration in the Barcelona harbour (BLASCO, 1973) and Chattonella sp. caused a bloom in the Ebre Delta, 1n 1990 (DELGADO, pers. com.).

One of the species most commonly implicated in massive red tides in the Mediterranean area is the dinoflagellate Noctiluca scintillans. This large heterotrophic organism is common in many marine areas of the world. Noctiluca red tide patches give a bright red coloration to the water and may be very extense. LÓPEZ and ARTE (1971, 1972) describe the development of large Noctiluca red tides in the Catalan coast (Spain) in 1970 and 1971. In the northern part of this zone, at L'Estartit, large patches of coloured water presumably caused by Noctiluca have been observed in 10 of the years between 1970 and 1993 (J. PASCUAL, pers. com.). Their time of appearance ranged from late February to mid May. In 1986, a Noctiluca red tide stretched from Cape Creus and the Bay of Rosas to more than 120 Km south, past Barcelona (CRUZADO, 1990).

4. Harmful effects

Basically, two types of harmful effects can be distinguished (ACMP, 1991):
1) Events caused by toxic species, which may be present or not at high abundances.
2) Harmful effects associated to the presence of high biomass of non-toxic species.

4.1-Toxic events

In general, human intoxications are due to ingestion of natural or cultured shellfish that has been feeding on toxic algae. The toxic episodes reported in Mediterranean waters include PSP (paralytic shellfish poisoning), DSP (diarrhetic shellfish poisoning) and fish and marine fauna mortalities. Other types of toxicity, such as NSP (neurotoxic shellfish poisoning) and ASP (amnesic shellfish poisoning) have not been reported yet the Mediterranean waters, but possibility of appearance should be kept in mind. Toxic effects on cultured fish ans shellfish have been associated with high abundances of some dinoflagellate species (Table 1).

PSP occurs in humans (and other vertebrates) after ingestion of mussels and other bivalves which have been feeding on dinoflagellates which produce neurotoxins of the saxitoxin group. PSP has only recently been reported in the Mediterranean (BRAVO *et al.*, 1990; DELGADO *et al.*, 1990); the causative organisms were Alexandrium minutum and Gymnodinium catenatum. Suspected toxicity of Gonyaulax polyedra (BRUNO *et al.*, 1990) has not been confirmed.

DSP toxins cause gastrointestinal disturbances lasting for 2-3 days. The toxins involved are mainly okadaic acid and two dinophysistoxins. The main DSP producing organisms, Dinophysis spp., are widespread in the Mediterranean.

Mortality of shellfish after the appearance of Gyrodinium spirale has been observed in the Thau lagoon, in southern France. However, there was not enough evidence to attribute direct toxicity to this species (SOURNIA *et al.*, 1991). A similar episode in the Bou lagoon, in Tunisia, was associated with an apparently toxic Gymnodinium sp. (GENTIEN, pers. com.). Fish kills in brackish coastal lagoons of the Ebre Delta (COMIN and FERRER, 1978) and other places have been caused by Prymnesium parvum, an haptophyte which produces a toxin related to that of Chrysochromulina polylepis.

4.2-High biomass effects

Harmful effects not directly related to toxicity include anoxia, due to oxygen consumption by decaying organic matter, which may lead to mortality of benthic organisms and fish. Other effects are mechanical, such as the irritation of fish gills. The intense production of mucus which may occur under certain conditions (Phaeocystis blooms and mucilage episodes of "mare sporco", for example) may produce clogging of fishing nets and aestetic impacts affecting tourism.

- Anoxia problems

In the Northern Adriatic, massive kills of fish and benthic marine fauna due to anoxia were reported in 1975 (MANCINI *et al.*, 1980) and in later years (STEFANON and BOLDRIN, 1982). These episodes have been caused by assemblages of diatoms ar dinoflagellates, or by both groups together (MARCHETTI, 1992). In spite of their spectacularity, Noctiluca red tides have only rarely been associated with fish mortality by anoxia (ACMP, 1991).

-Mucilage problems

Apart of the occurrence of elevated amounts of algal biomass, another problem to be considered is the hyperproduction of extracellular secretion compounds which may form accumulations of "gels" or "mucilages". The accumulation of gel-like material produced by Phaeocystis in the beaches of Benicàssim (Castelló, Spain), in July 1990, caused economic losses in the touristic sector. Similar problems, although not related to plankton, have occurred in the coasts of Catalunya and Valencia, due to the occasional accumalation of detached seaweeds. These cases will not be dealt with here.

A particular problem of mucilage production, popularly known as "mare sporco" has been occurring for a long time in the Adriatic (FONDA-UMANI *et al.* 1989; REVELANTE and GILMARTIN, 1991; MOLIN *et al.*, 1992), but reached extraordinary proportions in 1988 and 1989 (MARCHETTI, 1992). This phenomenon is due to polysaccharide products normally excreted by algal cells, which, for reasons that are not completely clear, can accumulate in enormous amounts, producing important losses to fishing and touristic activities. One of possible factors enhancing gel production could be phosphorus limitation, a condition likely to occur in the Adriatic. One possibility is that amorphous aggregates ("marine snow") are formed to some extent every year, as in other marine regions, but certain conditions of nutrient load ratios, weather and hydrography (calm sea, weak currents) can lead to occasional hyperproduction and aggregation in large masses (MARCHETTI, 1992). The most common belief is that the mucilage is produced mainly by benthic diatoms, which are often very numerous in the gelatinous masses. However, according to HERNDL *et al.* (1992), benthic microphytobenthos cannot account for the high abundance of marine snow during summer, and its principal source would be ungrazed, decaying phytoplankton. Sinking of these decaying cells would be retarded at the pycnocline. This retention would favour aggregation in larger masses, creating a "false benthos" which could become positively buoyant due to the metabolic activity of the microorganisms embedded in the marine snow. The entire layer could eventually rise to the surface. This aggregate formation mechanism would be favoured also by calm and stable weather conditions. Storm-induced mixing of the water column in the fall and activation of the southern Adriatic current (RINALDI *et al.*, 1990) end up breaking and dispersing the mucilages.

The episodes of massive mucilage formation in the Northern Adriatic appear to be favoured by some particularities of this water body. Among them can be considered its shallowness (<35 m), the low turbulence during the summer and the high riverine nutrient input (DEGOBBIS, 1989). However, mucilage events are not unique to the Adriatic, and similar aggregates, although in much smaller amounts have caused occasional concern in zones such as the Bays of the Ebre Delta (DELGADO, pers. com.), which present similar conditions at a small scale.

5. Important toxic species in the Mediterranean region

As stated above, some species are harmful due to direct toxic effects. However, for reasons that are not clearly understood and may depend on the strain involved and/or on environmental conditions, some forms may be more or less toxic or completely non toxic. Authors like SILVA (1980) and KODAMA (1990) have suggested the possible implication of symbiotic bacteria in some cases of algal toxicity. Table 1 lists some potentially toxic phytoplankton taxa which have been reported in Mediterranean waters. The following paragraphs deal with the most important ones.

<u>Alexandrium</u> spp.

This genus includes a series of forms of difficult classification, previously described within the group tamarense of the genus Gonyaulax (BALECH, 1985; 1990). The type species, Alexandrium minutum was described by HALIM (1960) after it formed a red tide in the harbour of Alexandria (Egipt). Alexandrium species produce benthic cysts, which may be important in the initiation of regional blooms (ANDERSON and KEAFER, 1985; THERRIAULT et al, 1985). Several Alexandrium species (among them, A. acatenella, A. catenella, A. excavatum, A. fundyense, A. minutum and A. tamarense) have caused PSP episodes in many marine areas of the world (ICES, 1992). However, toxicity varies widely among populations from different regions and even within a single isolate in different growth stages (MARANDA *et al.*, 1985; CEMBELLA *et al.*, 1988). Phosphorus limitation at low temperatures appears to enhance toxicity (BOYER *et al.*, 1987). One of the first PSP outbreaks reported in the Mediterranean area occurred in the Ebre Delta region (Eastern coast of Spain), in association with a bloom of A. minutum (DELGADO *et al.*, 1990). A. cf. minutum has also caused PSP episodes (BELIN and BERTHOME, 1991) in the Languedoc coast (Toulon, France). A. Balechii, A. tamarense and A. minutum have been found in the Gulfs of Naples and Salerno (Tyrrhenian), without appearance of PSP cases (MONTRESOR *et al.*, 1990). A. minutum has caused red tides in the Bay of Izmir (Turkey), but no clear evidence of PSP has been reported (KORAY, 1990, 1992). Several Alexandrium species, A. pseudogonyaulax, A. tamarense, A. cf. fundyense, A. minutum and A. lusitanicum (possibly a variety of A. minutum, rather than a different species) have been recorded in the Adriatic, again without association with PSP (BONI *et al.*, 1986; HONSELL *et al.*, 1992).

Dinophysis spp.

This genus includes several species (among them D. acuta, D. acuminata, D. fortii, D. sacculus, D. tripos) which have been associated with DSP outbreaks (BONI *et al.*, 1992; BELIN and BERTHOME, 1991; BONI *et al.*, 1992; HONSELL *et al.*, 1992; SOURNIA *et al.*, 1991; FATTORUSSO *et al.*, 1992) in mussels of the northern Adriatic Sea and Languedoc-Roussillon coasts (France). Although toxicity has been proved by direct analysis of Dinophysis cells (LEE *et al.*, 1989), there is a large variation in toxin concentration and, in many cases, no clear relationships have been established between DSP toxin levels in shellfish and concentration of Dinophysis spp. (ACMP, 1991). In some cases, as few as 50-200 cells/l may cause toxicity. In other occasions, much higher concentrations fail to produce toxicity, as happens in the Ebre Delta region (M. DELGADO, pers. com.). Dinophysis spp. tend to be more abundant, but without reaching bloom concentrations, from summer to fall. Some groups of species, such as D. acuminata and D. sacculus present intermediate forms, and their status as separate species is under discussion.

Gymnodinium catenatum

This PSP producing dinoflagellate forms characteristic chains which may include more than 40 cells and presents benthic cysts. First described by GRAHAM (1943) in the Gulf of California, it was found in 1976 in the Galician rías, in association with a PSP outbreak (ESTRADA *et al.*, 1984). Given its size and typical aspect, it is unlikely that it had been previously overlooked in the zone, where it was presumably a new introduction. At present, G. catenatum is found in many marine areas of the world. The presence of G. catenatum in the Mediterranean Sea was noted for the first time in the Malaga coast, in southern Spain (BRAVO *et al.*, 1990). A small form of G. catenatum has been reported in the Fusaro lagoon (Italy) by CARRADA *et al.*, 1988, in the Adriatic (HONSELL *et al.*, 1992) and in the coast of Valencia, in Spain (DELGADO, pers. com.). This small form appears to be non-toxic; its relationship with the typical G. catenatum is presently under revision (DELGADO and FRAGA, pers. com.). A Gymnodinium catenatum-like species has been also reported from Aegean coastal waters (FRILIGOS and GOTSIS-SKRETAS, 1989).

6.-Trends in algal bloom incidence. Role of nutrients.

The role of nutrients in phytoplankton bloom events has been reviewed recently by several working groups. A concise discussion, prepared by the Working Group on Phytoplankton and the Management of their Effects, of ICES, can be found in ACMP (1991). Other aspects of this problem are discussed in BARTH and FEGAN, 1990 and VOLLENWEIDER *et al.*, 1992. In general, however, evaluation of possible trends in bloom-related phenomena in the Mediterranean and elsewhere is hindered by the lack of adequate time series of data.

At present, there is evidence that increased occurrence and intensity of blooms of non toxic algae may be associated to nutrient enrichment. This is the case of the Pheocystis blooms in Dutch coastal waters and of red tides in Hong Kong harbour and the Inland Sea of Japan. In the Northern Adriatic, increased nutrient loads from the Po and minor rivers in the last two decades appear to have favoured the production of algal blooms (DEGOBBIS, 1990; VOLLENWEIDER *et al.*, 1992; MARCHETTI, 1992). However, no significant changes in nutrient levels were found between 1984 and 1989, and it seems that nutrient concentrations, at least in terms of average levels did not play a significant role in the massive mucilage formation of 1988 and 1989 (WARREN *et al.*, 1992). Nevertheless, the authors admitted the possibility of some nutrient imbalance due to dry weather and reduced river flow in critical periods of these years.

There is no convincing evidence linking blooms of toxic algal species with anthropogenic nutrient enrichment. Reports of toxic episodes may have increased due to the spread of aquaculture and increased environmental awareness which have lead to the establishment of regular phytoplankton monitoring programs. However, human activities may have contributed to the dispersal of some species. This seems to be the case of Gymnodinium catenatum, transferred from Japan to Tasmania in ballast waters of ship (HALLEGRAEFF, *et al.*, 1990).

In spite of the lack of direct association between eutrophication and toxic phenomena, anthropogenic inputs of macro- and micronutrients can lead to increased standing stocks of both toxic and non-toxic species. Another possibility are "nutrient ratio" effects. For example, a preferential supply of N and P could allow selective growth of non diatom species after silicon exhaustion. Differences in nutrient limitation can modify toxicity levels in certain species.

7. Socio-economic impact

In terms of socio-economic concerns, human health is the most important. Measures taken in order to protect the public may range from temporary or permanent closure of a particular area for shellfish harvesting or aquaculture, to the establishment of monitoring programs to ensure the safety of the products. The adopted approach will depend on the value of the affected resources.

-Aquaculture

The economic impacts on shellfish aquaculture derive principally from the need to pay for monitoring programmes and from the temporary closure of exploitations due to presence of PSP and DSP toxicity at levels unacceptable for human consumption. For example, during the PSP episode of May 1989 in the Ebre Delta, harvesting of mussels was suspended for about one month (DELGADO *et al.*, 1990). According to one estimation (J. CAMP, pers. com.), about 1500 Tm of mussels, i. e., half of the yearly production, with an economical value of approximately 1.1 $*10^6$ ECU, could have been lost due to the PSP outbreak.

DSP toxicity has been a problem mainly in southwestern France (LASSU and MARCAILLOU-LE BAUT, 1991) and in the Adriatic. The first cases of diarrhetic shellfish poisoning in this sea occurred in 1989, after consumption of natural or cultivated shellfish. Biotoxicological tests showed the presence of toxicity exceeding the risk level in mussels and consumption was banned for many weeks (VOLTERRA *et al.*, 1991; BONI *et al.*, 1992).

Other detrimental effects of algae on aquaculture are due to mortality of bivalve "seed" and cultured fish caused by anoxia or direct toxicity (GUENOLE *et al.*, 1983; PEREZ CAMACHO, 1989). Occasional fish kills have been reported in coastal lagoons of the Ebre Delta used for aquaculture (COMIN and FERRER, 1978; J. CAMP, pers. com). In September 1991, a farm located in the Bou lagoon (Tunisia) lost 3* 10^6 ECU of fish due to a Gymnodinium sp. bloom (P. GENTIEN, pers. com.).

More important than the blooms themselves is often the misinformation which accompanies them (SHUMWAY, 1990). Unaccurate news media coverage, failure to distinguish between affected and unaffected species or areas may cause unnecessary economical losses, as has been documented in some regions (JENSEN, 1975). SHUMWAY (1990) describes several examples of "halo" effects and the efforts of countries like Canada to overcome them with public awareness campaigns.

-Fisheries

It should be noted that the very conditions which favour accumulation of dense phytoplankton populations and, therefore, the appearance of harmful plankton blooms, are those responsible for the high fisheries potential of some zones. This is the case of the Adriatic, which contributed about half all Italian catches in the period 1982-1987 (BOMBACE, 1992). However, from 1982 to 1987, the catch per unit effort in the northern Adriatic was halved. This trend has been attributed to hypo- and anoxia in the sea bed (BOMBACE, 1992). Prolonged stratification, with or without algal blooms appears to have been the main cause of the anoxia crises.

Another problem which occurs in the Adriatic and to less extent in other Mediterranean areas, is the clogging of fishing nets by mucilage or other biological materials. This nuisance is not always due to phytoplankton products; accumulation of detached seaweeds or gelatinous zooplankton (salps) are also common causes.

-<u>Tourism</u>

Apart of possible threats to human health, presence of mucilage and any phenomenon affecting transparency and other properties of the water in coastal zones is likely to have great impact on tourism, which is looking for recreational activities in an attractive environment. However, it should be noted here that the tourism industry itself, has been one of the main causes of anthropogenic aggression to the Mediterranean coastal environment.

The economic impact of abnormal blooms on tourism is very difficult to evaluate, because touristic activities respond to many other variables, apart of environmental aspects. According to VOLTERRA and KERR (1992), declining tourism in areas like the Adriatic coast of Italy is an established fact. The problems in other zones have been more sporadic, making still more difficult an estimation of the associated economical losses.

8. Possibilities for control through reduction of nutrient loads

Efforts to reduce nutrient loads could be expected to be particularly useful in cases of a general increase of biomass production by a variety of species. It should be taken into account, however, that physical factors such as mixing and water exchange rates may have an overriding importance in the appearance or not of biomass accumulations. Possible measures have been reviewed by PAGNOTTA and PUDDU (1990) and VOLLENWEIDER (1992), and are summarized in WARREN (1992). According to VOLLENWEIDER (1992), the only viable strategy is to reduce the nutrient loads at their source (e. g. rationalisation of industrial and agricultural production cycles).

Alternate remedial options are deep water disposal and diffusion of treated urban sewage and temporary lagooning with treatment of sewage waters before releasing them. Direct "cosmetic" interventions such as confinement of algal blooms and removal of material have temporary effects and are only practical in emergence situations at localized spots (VOLLENWEIDER, 1992). Some estimates of economic costs of nutrient control measures for the northern Adriatic are given in Chiaudani and Premazzi (1988) and REUSS (1990). The possibility of "nutrient ratio" effects on toxicity or mucilage production has clear implications for management of nutrient loads to coastal waters. Reduction of P, for example, could lead to higher toxicity of some species.

9. Management strategies in aquaculture

In the case of aquaculture operations, management strategies should begin with an adequate selection of the site (ICES, 1992). This involves finding a compromise between a desirable high productivity of the area, and the likelihood of appearance of harmful blooms. Historical records of phytoplankton composition and previous knowledge of the oceanographic conditions in the zone may be important for a successful site selection. Careful selection of species and culture methods may help to reduce toxicity problems.

Management strategies for existing aquaculture operations are based on 1) farm design, 2) monitoring for the presence of harmful species, with of without blooms and 3) techniques to be used when the presence of harmful species has been detected (ICES, 1992).

Once a toxic outbreak has occurred, shellfish will eventually lose the toxicity if maintained in water free of toxic organisms; however, this process may last for weeks or months. Some attempts to use ozone for decontamination have given non-conclusive results (SHUMWAY, 1990).

10. Monitoring

The goal of monitoring programs is to provide early warning of the occurrence of possible problems and to protect public health. Effective monitoring strategies need to be based on previous knowledge of the hydrographic and ecological conditions in the area of interest. If such information does not exist, an adequate study program should be implemented. Once basic information is available, a sampling scheme can be designed to be as cost effective as possible. There are two main aspects of monitoring: for phytoplankton and for the presence of toxins. More detailed information can be found in ICES (1992).

11. Regulation

Mandatory phycotoxin control in cultured shellfish exists in many countries of the world, including several Mediterranean ones (France, Italy, Spain), although there are methodological differences. General requirements for shellfish quality have been implemented in EEC countries. In general, monitoring is carried out by government agencies. However, in some non-Mediterranean countries, like Denmark or Sweden, the fishermen or processors are responsible for ensuring the safety of their shellfish and must bear the cost of the analyses.

12. Prediction of harmful occurrences

At present, there are no reliable tools for predicting or anticipating the occurrence and abundance of a particular phytoplankton species, although there are models for predicting the evolution of phytoplankton biomass, given certain hydrodynamical situations (e. g. DIPPNER, 1990). However, some approaches may help to estimate the probability of harmful events, including toxicity or mucilage problems. One possibility is the collection of time series data of environmental variables and phytoplankton composition and analyse them, looking for the presence of consistent relationships concerning time of appearance and spatial patterns of the harmful occurrences.

13. Priority issues for research

Research priorities concerning harmful algal blooms have been outlined in the report IOC-FAO/IPHAB-I/3, of the IOC (Intergovernmental Oceanographic

Commission)-FAO Panel on Harmful Algal Blooms (HAB). A program of research activities in relationship with the Mediterranean marine environment is included in the Mediterranean Action Plan (UNEP, 1985; Saverio CIVILI, 1990). Aspects concerning the problems of the Adriatic Sea are discussed in the conclusions of BARTH and FEGAN (1990).

Several of these points have been approached in international research projects funded by European programmes such as Environment, MAST and BCR, of the EEC. The Avicena program, also of the EEC, is devoted to cooperations with non-EEC Mediterranean countries.

14. Information and communication issues

Several international organisations are making efforts to coordinate and distribute information on harmful algal occurrences. The "Commission Internationale pour l'exploration scientifique de la Mer Méditerranée" produces yearly reports summarizing the published work dealing with plankton in the Mediterranean. IOC edits the Newletter "Harmful Algae News", which offers up to date information on toxic algae and algal blooms. Several Working Groups of ICES, the Advisory Committee on Marine Pollution (to be replaced by the Advisory Committee on the Marine Environment), of ICES, and the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), of IOC/UNESCO, publish reports concerning harmful algal questions. The possibility of establishing an appropriate data bank on harmful phytoplankton has been discussed by the Working Group on Phytoplankton and the Management of their Effects (ICES) but no conclusions have been reached yet.

15. Conclusion

There is great interest worldwide on the scientific study and management of harmful events associated with phytoplankton. Appropriate recommendations on possible approaches exist already. The challenge for many Mediterranen countries is to take the necessary polytical and economical decissions to make a relevant contribution to the existing problems.

16. Recommendations for action

1- Eutrophication-related problems. (Note that not all algal blooms are related to anthropogenic eutrophication):

1.1-Identify vulnerable areas

1.2-Estimate nutrient inputs to these areas

1.3-Reduce the sources of nutrient loads (e.g.reconsider industrial processes and rationalize use of fertilizers in agriculture)

1.4-Treatment of nutrient-rich waste waters (including steps to reduce N and P, but attention to nutrient ratio effects)

1.5-Stop destruction and drainage of wetlands

1.6-Increase flushing

1.7-Develop appropriate international agreements and legislation.

2- Mucilage problems. Reduction of nutrient loads may help in some areas. It is not clear that this may be the case in the Adriatic, but reduction of nutrient loads there is desirable to reduce the high biomass problems.

2.1-More research.

3- Aquaculture problems

3.1-Careful site, species and method selection

3.2-Long term monitoring

3.3-Improve methods of toxin analysis

3.4-More research on taxonomy, physiology and population dynamics of the causative organisms.

3.5-Improve dissemination of information

Table 1.- List of important potentially harmful taxa found in Mediterranean waters.

TAXA	POTENTIAL HARMFUL EFFECTS
Alexandrium spp.	PSP
Dinophysis spp.	DSP
Gymnodinium catenatum	PSP
Gymnodinium spp.	Fish mortality.
Gyrodinium spirale	Shellfish mortality
Noctiluca scintillans	Fish mortality by anoxia
Nitzschia pungens	ASP
Prorocentrum lima	DSP. Ciguatera?
Prorocentrum mexicanum	DSP. Ciguatera?
Prorocentrum minimum	Early reports of toxicity but no evidence of toxic effects in the Mediteranean
Prymnesium parvum	Fish mortality

Trends in Mediterranean fisheries yields

by Jordi LLEONART

Institut de Ciències del Mar, Paseo Nacional, s/n 08039 - Barcelona, Spain

Introduction

Fishing has a long tradition in the Mediterranean countries, and many extractive methods have developped there from ancient times. This historical and cultural background is the cause of the diversity of the gears in use and the significance of so many small artisanal fisheries that are found along the Mediterranean seashore. This tradition no doubt hampers the improvement of fishing practices. The expressions "diverse" and "few but expensive" may describe the Mediterranean fisheries in the simplest form. General works dealing with Mediterranean fisheries and related topics can be found in MARGALEF (1985), CADDY (1990), CADDY and GRIFFITHS (1990) and Charbonier *et al.* (1990).

Ecology and fisheries

Some studies on relationships between ecosystem and fishing have been recently carried out by the Mediterranean Action Plan, sponsored by UNEP (CHARBONNIER *et al.*, 1990) and ICES, the International Council for the Exploration of the Sea (ANON, 1992). Although this last work is devoted to the problems of the North-eastern Atlantic, and particularly to the North Sea, many of the conclusions reached can be easily transferred to the Mediterranean. The following paragraphs provide a synthesis of the conclusions of these studies. For details on the relevant ecology of the Mediterranean, in particular those of the western basin, the interested reader is refered to MARGALEF (1985).

Effects of fishing on environment

Fishing modifies the environment, frequently against its own benefit. Fishing not only reduces the abundance of the target population, but also, as a secondary effect, that of other biota, directly affecting the relative composition of species, both commercial and non commercial, in the exploited community. Fishing gears have different selection rates for different species and lengths. In consequence the ecosystem is simplified by reduction of energetic pathways and the decrease of number of species (CADDY & SHARP, 1986). An excessive fishing effort, or an inapropriate exploitation pattern, can produce dramatic effects on the whole ecosystem.

Several fishing activities can also degrade the seabed. Benthos can be severely damaged, or even destroyed, by the inappropriate use of dredges, trawls, and other bottom towed gears. The importance of such damage depends on the fishing intensity, on the sensitivity of the bottom, and on the type of damage produced by the gear. ROS *et al.* (1985), describe these substrates.

Seagrass beds (shallow meadows of marine phanerogams characteristic of the Mediterranean such as Zostera, Posidonia and Cymodocea) are rich and fragile ecosystems. They sustain particular communities with many organisms, some of them fishing targets, and act as nurseries of other organisms. They can support a fishing activity with non agressive gears (i.e. basket traps), but are the most sensitive environments to the attacks of dragging and trawling. These meadows are found near the coast in shallow waters, and they are, with the rocky bottoms, the richest Mediterranean environments. Their recession is general along the Mediterranean and constitutes one clear priority for protection.

The rocky bottoms also support very rich and complex communities, but they are less vulnerable. Trawl cannot work on them, but the very destructive and forbidden dragging gear for coral is used on these bottoms. People are very sensitive to their degradation because of their importance in subaquatic tourism. Sandy and muddy bottoms are poorer environments, and dragging effects seem less serious.

Fishing indirectly affects the environment in various forms. It makes food available to other species of the ecosystem. This food can come from discards, which is very important in some cases, even in the Mediterranean. It comes also from induced mortality on individuals affected, but not caught, by gear. This can happen with animals passed through the meshes or escaped wounded from nets or hooks, that can die or become easy prey.

Another secundary effect is the so-called "ghost fishing", a phenomenon induced by lost-gears (mainly nets or traps) that may continue fishing during a time after being lost.

Impact of anthropogenic factors, other than fishing, on ecological systems, and their effect on fisheries

Much has been written about pollution in the Mediterranean, but little is known about how the different pollutants can affect fisheries. It seems clear that pollution mainly affects the coastal fishing resources. Fish mortalities have been reported in harbours, deltas and coastal and estuarine lagoons, due to fertilizants, insecticides, and anoxia or hypoxia produced by organic matter. Eutrophication seems to alter the energetic balance and can produce biomass blooms of organisms, which are not always of commercial interest (as medusae).

Nevertheless it can be asserted that in the Mediterranean the touristic activity represents a pollution source as important as the industry and agriculture. In some parts of the Mediterranean coast, where the tourism is dominant, the proliferation of marinas has destroyed a quantity of shallow ecosystems, and has altered the coastal dynamics, making the beaches desappear. As a result artificial sand transports from shallow waters to the beach is frequently needed, destroying sandy ecosystems and exploitable resources (mainly composed by shellfish).
The disturbance suffered by shallow sensitive environments due to the massive presence of subaquatic recreative activities, is a constant threat on the stability of such ecosystems.

Description of the fisheries

Every year FAO publishes, with a two-year delay, the World fishing statistics. The last isue (FAO, 1992) corresponds to 1990. According to this document the total marine catches reported in the Mediterranean and Black seas reached almost 1.5 million tonnes. This figure represents 1.79% of the World catches (near 83 million tonnes). One recalls that the surface of our sea represents only 0.8% of the world marine surface.

However, fishing activity does not regularly spread on the whole sea surface, it rather appears to be concentrated on the shelf. Thus fishing in open sea on depths greater than 400 m is uncommon and only adequate for some particular fisheries. In 1985 FAO published an Atlas where the resource distribution in central and western Mediterranean can be observed.

The shelfs are very narrow in almost all Mediterranean shores. Only the Adriatic, the gulf of Gabès, and some other smaller areas (see figure 1), present extense fishing grounds and are very much productive.

In Figure 2 the catch trends followed by EEC and other (non Black Sea) countries are shown. The countries of the northern shore, in particular those of the EEC, have a more or less stable trajectory while for the "others", including those of the southern part of the Mediterranean, continuous increasing trends are patent. Note the high Italian catches and the local 1985 maximum. In Table 1, the FAO (1992) statistics corresponding to the Mediterranean, now with the Black sea included, are presented. Some general comments on these issues can be found in BAS *et al.* (1985), CADDY & GRIFFITHS (1990) and Charbonier *et al.* (1990). In figure 3 a chart and some very general numbers for 1987 taken from this last author are presented.

Better accuracy is needed in order to properly assess the actual condition of the Mediterranean fisheries, or at least provide a considered opinion:

The demersal resource

Are known as demersal those organisms living near the bottom. Many commercial species (more than 100) belong to this group. Among the fishes the main ones are hake, red mullets, whitings, seabasses, congers, porgies and seabreams, soles, flatfishes, anglerfish, etc. The exploited crustaceans are crabs, prawns, lobsters, and shrimps, and among the molluscs, octopusses, cuttlefish, oysters, stripped venus, donax clam, carpet shell, and mussels, are the most important.

There are also a lot of gears exploiting these resources. The main ones are bottom trawls, gillnets, trammel nets, traps, and bottom longlines. The depths exploited can range from 0 m to 800, but mainly from 0 to 400 mm.

The demersal fisheries are generally multispecific, representing near 55% of the total catches, but catches per hour are small, heterogeneous and diverse, and, usually, have a high price. "Few but expensive" can define the demersal Mediterranean fihsery. In

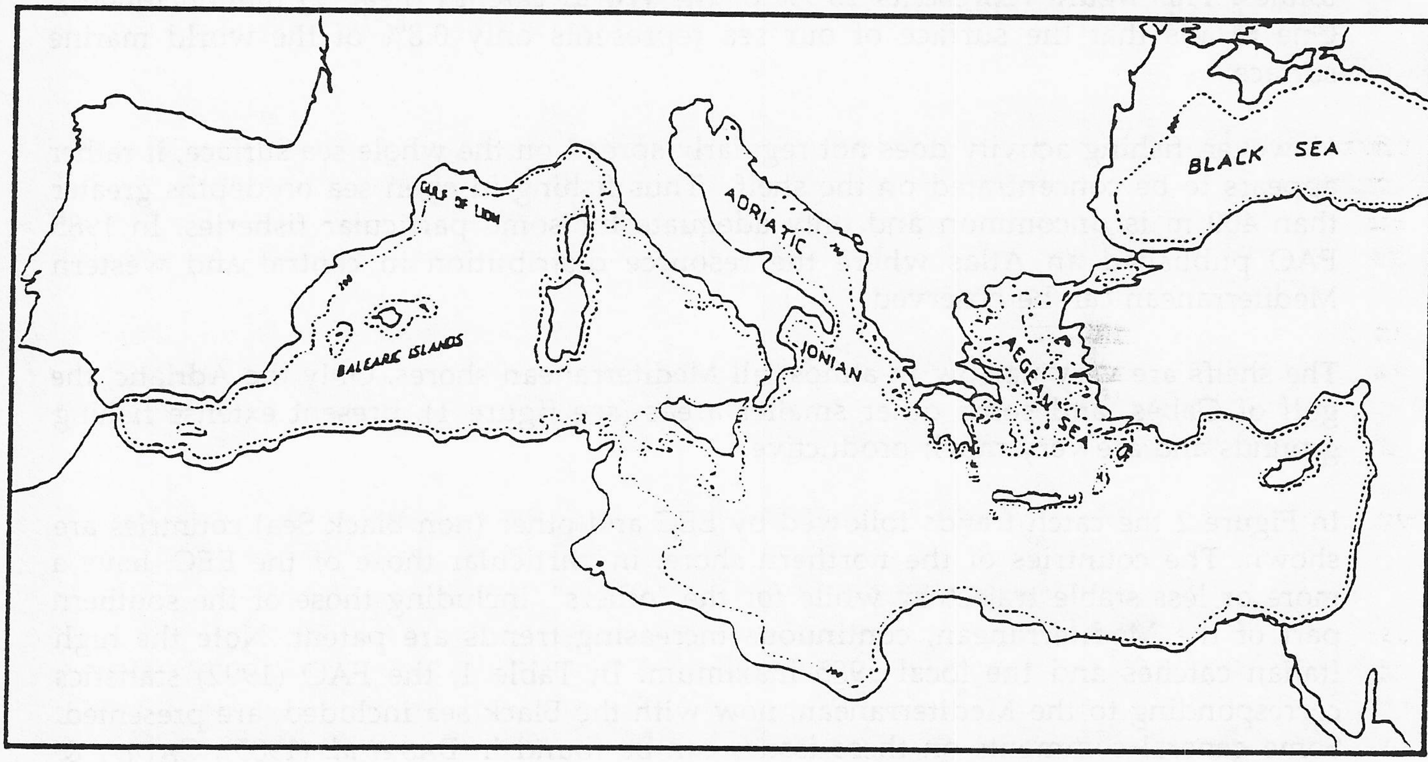


FIGURE 1. The Mediterranean region. CADDY (1990)

general it can be considered to be overexploited.

Bottom trawl is the main demersal gear in terms of number of vessels, fishing effort and catches obtained. It is very aggressive to the seabed, and has a bad selectivity pattern (wide length ranges of many species are catchable by it). Furthermore it competes advantageously with other more specialized gears.

Small pelagics

These are fishes living in midwater or near the surface. Usually their length does not exceed 20 cm, and their lifespan does not exceed a few years. They form schools composed of many individuals. The procedures used by fishermen to catch small pelagics take advantage of the gregarious behaviour of these fish.

A few species are commercial, anchovy and pilchard being the main ones, but others, usually a little bit larger, as all mackerels, bogue, bonito and some squids, account for significant catches. Despite the fact that the number of pelagic species is much lower than the demersals, their catches represent around 40% of total catches.

Pelagic trawl and purse seine are the proper gears to catch this fish. Fishermen search schools actively, using modern technologies. The price per unit of this resource is not high, but due to the great quantities caught it has much economic importance.

Stock evaluation are currently done by acoustic methods rather than indirect or population dynamics methods.

In general small pelagic populations are highly dependent on recruitment. The longevity of their individuals is short, and since they live, in their larval and juvenile forms, in a very variable environment, predictions about their population dynamics are quite uncertain and large fluctuations of their biomass have been reported many times. This trend is cited sometimes to assert that management of small pelagics is not possible. Dramatic collapses of small pelagic stocks around the world, where fishing was significant, invalidate this argument. Even in the Mediterranean the anchovy stock of Alboran sea collapsed after a intensive fishing of immatures.

Large pelagics

These are fishes living near the surface, large in length, migrants and gregarious. Swordfish, several species of tunas, and pelagic sharks fiigure in this group.

They are caught mainly with seines, surface longlines, traps and gillnets. These last gears (and the seines) are considered as very destructive because of the accidental catches of turtles, mammals, birds, small swordfish, etc. Despite existing international agreements banning the use of surface drifting gilnets, their continuing use poses a major problem in the Mediterranean. Searching can be done using teledetection (aircrafts or satellites, see PETIT & STRETTA Eds., 1990). Large pelagic catches represent 4% of total catches.

In general their price is high and some species are very apreciated by the Japanese, and for this reason the Mediterranean fishing and markets have suffered some disturbances.

Due to their migrant habits trough the strait of Gibraltar (they spawn in the Mediterranean) their fishing assessment and management must be done, taking into account the information from both adjoining seas. This is the mission of ICCAT (International Commision for the Conservation of Atlantic Tunas) These species are considered to be overfished. In particular blue fin tuna adult populations of the east Atlantic and the Mediterranean have diminished more than 70% from the seventies.

Management

In the Mediterranean the maritime jurisdictions coincide with the 12 miles of territorial sea. Every country have its own fishing policy, often following the GFCM recommendations, but in general it can be asserted that the diversity, stated previously as a Mediterranean feature, is found also in the management policies.

Nevertheless most of the Mediterranean countries coincide in the protection of coastal shallow waters from trawling, so as to protect nurseries.

The International Organizations

There are several International organizations and agencies with a role in the Mediterranean fisheries.

The "General Fisheries Council for the Mediterranean" (GFCM) was created in 1949 by FAO. Its function is to promote the development, conservation and management of the Mediterranean fisheries. It can formulate and recommend management measures to the member states.

The "Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée" (CIESM) was created in 1919. It is a scientific forum where more than a thousand researchers working on the Mediterranean, including fisheries scientists, present their studies. It can also issue management recommendations or orientations to the authorities of its 21 Member States.

The Economic European Community (EEC), and its General Directorate XIV (Fisheries). Only four Mediterranean countries, but with the 67% of total catches, are affected by this organization.
The International Commission for the Conservation of Atlantic Tuna (ICCAT). Its mission is to assess and manage the large pelagic fisheries in the North Atlantic and the Mediterranean. Its action in the Mediterranean is problematic since many Mediterranean countries do not belong to ICCAT.

Stock assessment and data

Fisheries assessment is based on the use of mathematical models running with data of an actual fishery. Several models simulate quite well the dynamics and demography of the resource and have become an indispensable tool to diagnose the health of a resource, evaluate its potential, and recommend management policies.

But these models must be fitted with good real data, if something more than a mere theoretical exercice were required. Historical series of catches by species and efforts by gears, series of length frequencies of the main target species, biological parameters such as growth, reproductive characteristics, fecundity, length-weight relationships, are some of the main data needed to assess a fishery.

The scarcity of data about Mediterranean fisheries has been pointed out by almost all researchers. The problems of sampling are related with the wide diversity of species, and with the high cost of fish, frequently caught in small quantities by small vessels.

Management measures

There are many possible management measures. Here we briefly present the main ones with indications to Mediterranean application. Most of the regulations are adressed to bottom trawl since this gear is the most significant regarding demersal catches.

For all measures, the control and surveillance problem has to be taken into account. In the Mediterranean there are lots of excellent, but non enforced, measures.

Gear regulation. Several gears are banned in some countries while they are allowed in others. This phenomenon can even happen in different regions of a country. Prohibition, or rigorous limitation, of particularly destructive gears can be a good policy. Reconversion into more selective or less aggressive fishing practices can also yield good results.

Effort regulation. This is one of the most employed measures in the Mediterranean. The commonest mechanisms to regulate efforts are: limiting number of vessels, limiting total and individual power, and limiting the fishing time (days in a week or hours in a day).

Catch regulation. Can be done in different ways. The use of quotas or TACs (Total Allowable Catch), is the most used regulation measure in the Atlantic, but is almost absent in the Mediterranean, where the control and surveillance of TACs would be very difficult to carry out due to the structure of fleets and landing points. A regulation on catches frequently employed in the Mediterranean is prohibiting landing or commercialization of undersized fish. Most countries have lists of minimum sizes for several species.

Seasonal closures. A regulation measure frequently applied, but in some cases the grounds on which the season is decided are economical rather than biological.

Permanent protected zones. All countries protect the areas closest to the coast from trawling with the objective of preserving seabeds and nurseries. The surveillance is not always easy to do, and illegal trawling on these shallow waters yields very high profits. Artificial reefs are extensively used to assure protection against trawling.

Trawl mesh size regulation. The smaller mesh sizes in the world are found in the Mediterranean (CADDY, 1990). The goal of a 40 mm mesh size setd by the EEC, and by other agencies, is still far from reality in many Mediterranean countries. The relative high price of small fish, the existence of some small species that would not be caught, and the short-term losses that would occur as a result of increasing mesh size are the

FIG. 2

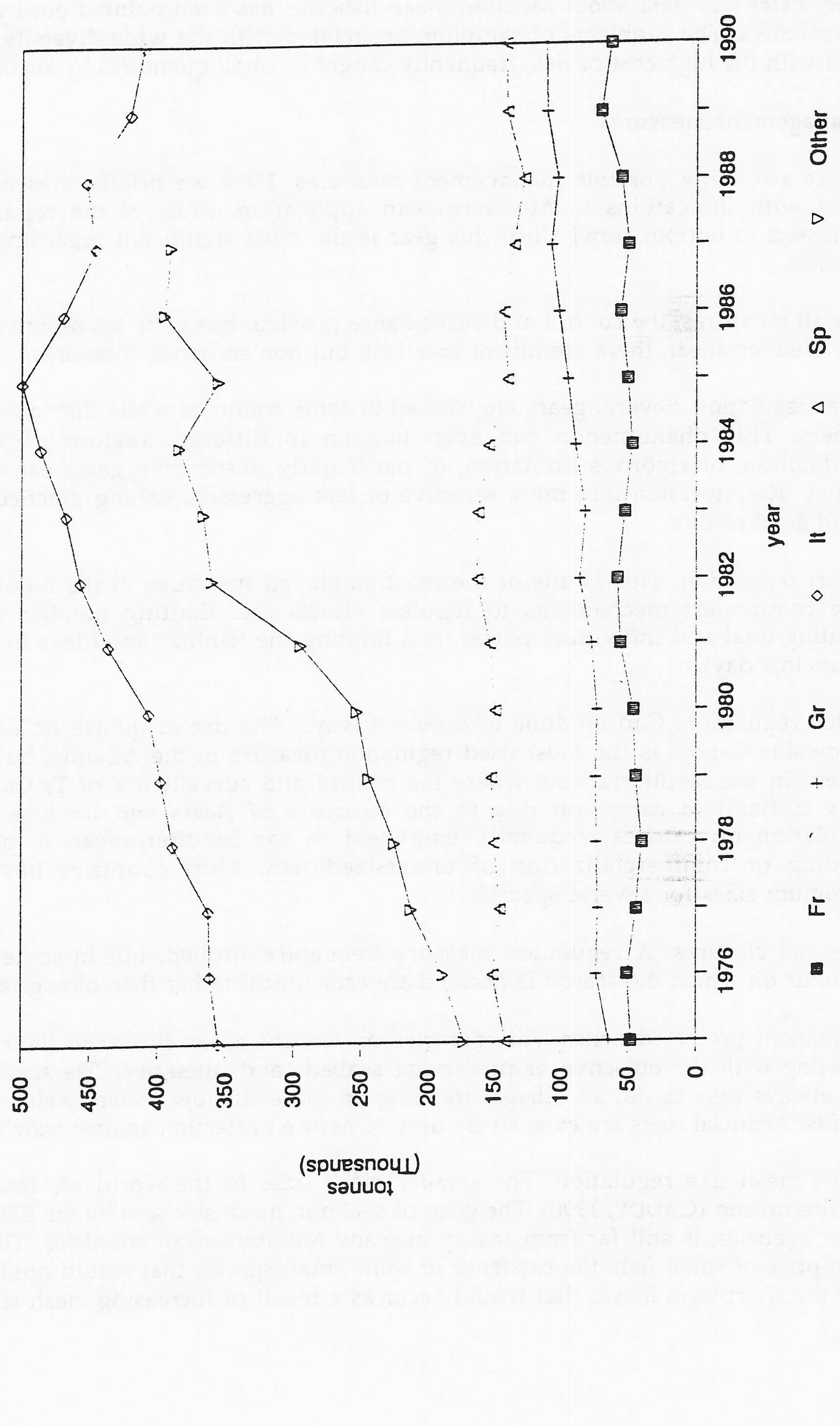
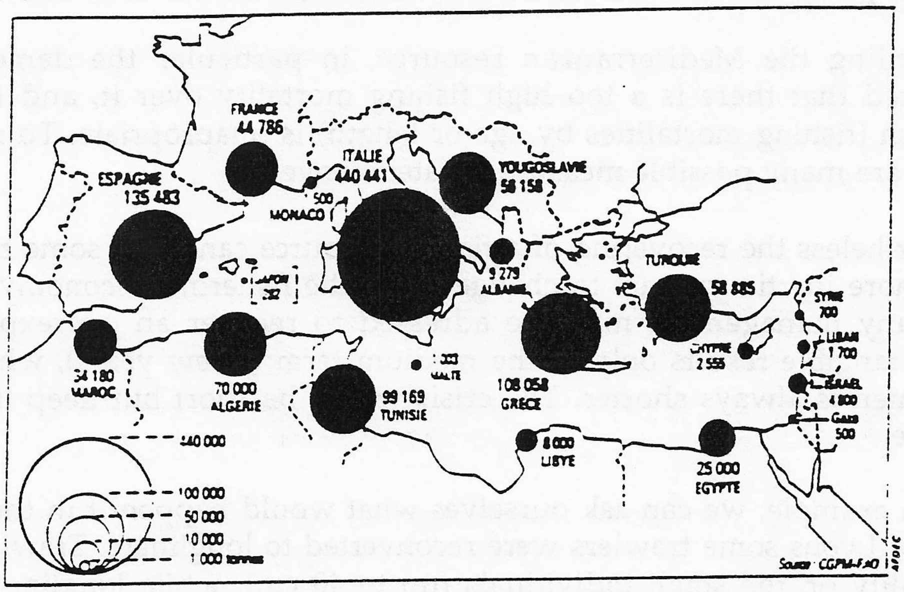

tonnes (Thousands)
500
450
400
350
300
250
200
150
100
50
0
year
1976
1978
1980
1982
1984
1986
1988
1990
Fr
Gr
It
Sp
Other

FIG. 3

Captures par pays ou zone en Méditerranée. en 1987



Captures totales (sauf thons) par sous-zones statistiques en 1987 (Tonnes)

Occidentale	Centrale	Orientale
386 887	483 309	174 530

Captures totales (sauf thons) par divisions statistiques en 1987 (Tonnes)

Baléares	G. du Lion	Sardaigne	Adriatique	Ionienne	Egée	Levant
201 332	74 131	111 424	253 628	229 681	125 836	48 694

Data furnished by Chaizonnier (1990)

main reasons that make difficult to apply this measure. Furthermore, the control and surveillance of actual mesh sizes requires the individual examination of vessels at sea.

Future perspectives for Mediterranean fisheries

Regarding the Mediterranean resource, in particular the demersal one, it can be asserted that there is a too high fishing mortality over it, and that the exploitation pattern (fishing mortalities by age or length) is unapropriate. To redress this situation there are many possible measures (stated above).

Nevertheless the recovering of a fishing resource can carry some trouble. The resource has more inertia to react to changes than the fishermen economy does, which means that any management measure adressed to recover an overexploited resource will yield tangible results only in the medium term (a few years), while the time scale of fishemen is always shorter. The crisis would be short but deep if the measures were severe.

As an example, we can ask ourselves what would happen if in the hake fishery of the gulf of Lyons some trawlers were reconverted to longliners. Trawlers stress the fishing mortality on the small individuals (up to 40 cm), while longline begins to fish from this length. In the Figure 4, the evolution of yield by boat under this assumption is shown. The final result is a general improvement of the fishery, but in the trends followed by both gears a deep longliner crisis can be seen. Similar results would appear if an enforcement of a wider mesh size was simulated.

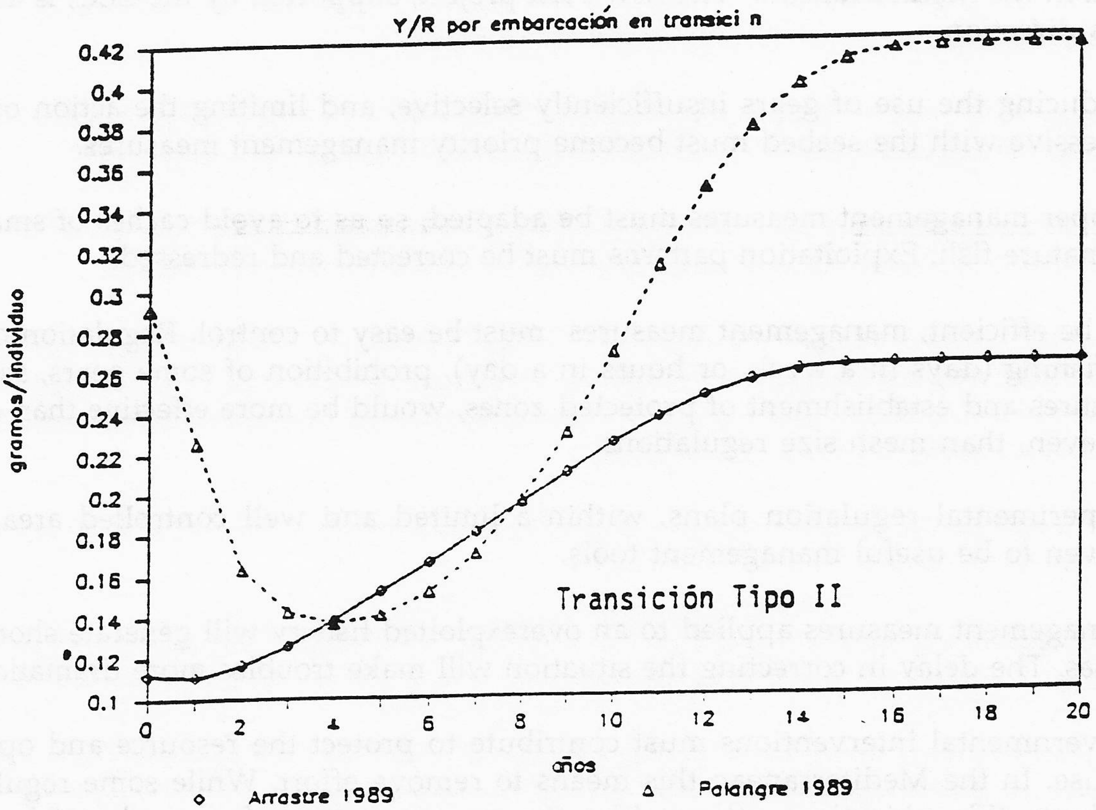
Predictions, and hence policies based on predictions, carry a considerable risk of inaccuracy. Fortunately, a few examples of successful fishery regulations in the Mediterranan can be found, in particular, the work carried out in the Spanish coast during the sixties, known as "Plan Experimental de Pesca" or "Plan Castellón" (SUAU, 1979), or the very attractive experience of Cyprus (Garcia and Demetropoulos, 1986). More recently the Italian regulation of the Adriatic fishery (GFCM, 1989) have shown that management measures are effective, particularly in reducing fishing mortality, and in improving the fishery's soundness.

At a smaller scale, the protection of limited zones has shown to be effective, as high rates of recovery have been observed. Nevertheless the existence of these small protected zones is frequently associated with the destruction of larger or more significant areas (i.e. building sportif ports), resulting in a worst final balance.

Some economical considerations

Studies on fisheries economics are scarce in the Mediterranean. Recently a working party was spensored by the GFCM (GFCM, 1992) where most of work done in Mediterranean countries was presented. Economists require, as biologists do, an improvement of statistics. Also some particular economical problems were identified. One of the worst is the existence of artificial mechanisms allowing to have benefits of overfishing. The carburant tax exemptions for fishing vessels, a common practice in many countries is a stimulus for fishermen to increase effort and has negative consequences on the preservation of the resource.

FIG. 4


Y/R por embarcación en transici n
gramos/individuo
0.42
0.4
0.38
0.36
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0
2
4
6
8
10
12
14
16
18
20
años
Transición Tipo II
Arrastre 1989
Palangre 1989

Conclusions

1. Singular ecological sensitive or threatened environments, such as seaweeds and rocky bottoms, as well as nursery areas, must be protected.

2. The data on Mediterranean fisheries are scarce and of bad quality. Getting good data, comparable between countries and sufficient for assessing purposes, is not an easy task in the Mediterranean. The new FAR project, supported by the EEC, is a step in this direction.

3. Reducing the use of gears insufficiently selective, and limiting the action of gears agressive with the seabed must become priority management measures.

4. Proper management measures must be adapted, so as to avoid caches of small and immature fish. Exploitation patterns must be corrected and redressed.

5. To be efficient, management measures must be easy to control. Regulation of time of fishing (days in a week, or hours in a day), prohibition of some gears, seasonal closures and establishment of protected zones, would be more effective than quotas or, even, than mesh size regulations.

6. Experimental regulation plans, within a limited and well controlled area, have proven to be useful management tools.

7. Management measures applied to an overexploited fishery will generate short term losses. The delay in correcting the situation will make troubles more dramatic.

8. Governmental interventions must contribute to protect the resource and optimize its use. In the Mediterranean this means to remove effort. While some regulations perform this objective, others, like the tax exemption for combustible, have counter-productive results, leading to an increase of the fishing efforts.

III - OPTIONS ET SOLUTIONS TECHNOLOGIQUES

Evaluation des technologies de restauration côtière

par Maria Caterina REDINI

Università degli Studi di Roma "La Sapienza", P.le Aldo Moro 5, 00185 Roma, Italia

La relation complexe qui existe entre les interventions anthropiques et l'environnement côtier demande forcément une conscience et une responsabilité majeures de la part des opérateurs qui travaillent sur le territoire et qui s'occupent des activités de planification, conception et réalisation des interventions. Tout cela est dû à la grande vulnérabilité des zones côtières face à la dégradation et à la pollution en raison de leur unicité et non reproductibilité.

La connaissance et l'utilisation correcte des techniques appropriées de "requalification", protection et réhabilitation des côtes, peuvent réduire de façon importante les risques de dégradation du paysage. Des choix technologiques non appropriés peuvent avoir des effets induits et destructeurs sur l'équilibre de l'environnement côtier. L'exactitude des interventions de transformation, d'un point de vue environnemental, la pertinence des solutions techniques adoptées doivent être proportionnées aux objectifs des interventions en fonction des caractéristiques du site.

Ce chapitre se concentre sur la relation entre les interventions anthropiques et l'environnement côtier méditerranéen dans des zones vulnérables. Il s'agit de zones uniques, caractérisées par la non-reproductibilité de leur ressources. Ce délicat mélange demande une plus grande conscience et responsabilité de la part des opérateurs du territoire.

Aujourd'hui, bien que la culture technologique ait atteint un haut niveau d'évolution et d'approfondissement, on peut constater l'existence de nombreuses situations de conflit non résolues entre la conservation, la mise en valeur et la productivité de ressources environnementales. Aussi bien la recherche que les offres du secteur des services technologiques n'arrivent à créer des systèmes de repères théoriques et d'application qui soient rapides, économiques et décisifs.

Nous n'avons pas trouvé dans la culture du secteur, dont les études analytiques sont très développées et très répandues, la contribution liée aux transformations morphologiques et d'images des sites sujets aux interventions technologiques et fonctionnelles. Nous entendons par là des études et des projets qui servent à expliquer le problème de la compatibilité entre les oeuvres de restauration à caractère sectoriel et la perception de l'image d'ensemble de la transformation. Et tout cela, là où le bien "zone côtière" est considéré comme patrimoine culturel, environnemental et économique.

L'analyse de l'environnement permet de découvrir quand et de quelle façon il convient d'intervenir dans une zone déterminée, qu'il s'agisse d'opérations de sauvegarde, de simple restauration ou de transformations.

Dans tous les cas, ces interventions doivent assurer le maintien des caractéristiques et des éléments qui ont produit un secteur particulier, qui ont une base dans la mémoire collective, qui nous font percevoir le paysage dans sa structure et dans son essence et qui en font un "bien original".

Le paysage est une création culturelle et il commence à être, à exister, lorsqu'il est perçu comme tel.

Etant donné que le paysage, et aussi les fragments qui se sont accumulés dans la mémoire, sont une ressource, il faut vérifier quelle partie du paysage peut être restaurée et quels fragments peuvent être transformés tout en sauvegardant la cohérence, la forme et la physionomie unitaire du paysage en question. Autrement dit, il s'agit de trouver une façon de travailler pour protéger l'identité et l'unicité d'un site.

Pour mener une étude technique de proposition avec ces objectifs, il faut travailler sur des zones côtières pilotes caractérisées par une présence de l'homme plus ou moins forte, et mener une analyse de l'environnement. L'analyse doit, avant tout, évaluer le niveau de dégradation afin de déterminer s'il vaut la peine d'intervenir. Le cas échéant, il sera possible de faire une vérification de réversibilité en accompagnant les résultats obtenus avec une enquête sur la disponibilité sociale.

Une recherche de ce type doit déterminer, en premier lieu, la "spécificité" des sites. Il s'agit de reconnaître les éléments principaux et les éléments qui sont perçus au niveau social : le niveau d'identification, c'est-à-dire la façon dans laquelle la collectivité se reconnaît dans un lieu. Il faut aussi analyser le potentiel de chaque zone côtière, c'est-à-dire sa dynamique due aux transformations. Pour sauvegarder les valeurs reconnues, améliorer la qualité de l'environnement et récupérer une cohabitation homme-nature là où tout cela est encore possible, nous pouvons indiquer deux techniques différentes :

- Techniques de perception, d'identification des éléments principaux de l'environnement physique, aussi bien naturels qu'artificiels, liés aux techniques plus appropriées pour la diffusion des résultats.

- Techniques particulières et sectorielles concernant les problèmes d'identification et de distribution des oeuvres et processus de transformation contrôlés. On peut créer des répertoires des interventions technologiques de conservation et sauvegarde des côtes. Il s'agit d'interventions de type morphologique, technique, de construction et d'organisation. Les interventions technologiques comprennent les interventions naturelles (conservation des dunes, travaux de reprise, travaux d'excavation) et les interventions artificielles ou mixtes articulées en relation à leur fonction de sauvegarde et à l'incidence sur l'environnement (sauvegarde passive, active, etc...).

L'application de deux techniques compatibles entre elles doit être simultanée afin d'éviter la pratique normale qui prévoit des interventions axées seulement sur la technologie.

Au sein des commissions d'étude responsables des contrôles et du développement des écosystèmes il arrive souvent que l'équipe soit formée par des experts (administrateurs, économistes, anthropologues, biologistes) qui s'occupent de la crédibilité des propositions pratiques et normatives. Très souvent, cette équipe ne comprend aucun spécialiste de l'image de l'environnement et de la restauration du territoire. Cette comparaison ne doit pas être faite après, mais il faut former des groupes intégrés qui travaillent sur les cas-échantillons. En général, au lieu de comparer des analyses, il vaut mieux déterminer des zones d'intervention dont les objectifs de recherche soient à même de fournir des stratégies d'interventions directes, plurisectorielles et compatibles entre elles. Dresser une liste des cas d'interventions, réussis ou non, faire la part entre les bons et les mauvais exemples n'est pas utile car très souvent des transformations du même genre sont dues à des facteurs différents, à des phénomènes non-homogènes. Au contraire, il serait intéressant d'établir quel a été le phénomène qui a causé la destruction de plusieurs zones côtières ou d'un paysage particulier.

La comparaison entre bons et mauvais exemples est nécessaire mais doit être bien orientée pour être efficace aussi bien du point de vue des mesures à appliquer que de la perception de la part des populations locales. La formation d'experts capables de faire les choix nécessaires est l'objectif principal. Il faut aussi développer une sensibilité particulière sur les questions de transformations de l'environnement en relation avec les trans-formations d'image.

Toutes ces considérations nous amènent à proposer une méthodologie d'étude qui ne soit pas limitée à la phase analytique, mais qui puisse l'intégrer avec des phases d'évaluation et de propositions. Le problème qui nous intéresse est la diffusion des résultats d'études qui doivent parvenir au grand public et aux décideurs. Ces derniers souvent s'intéressent aux possibilités économiques ou politiques d'une intervention, sans considérer la vocation d'un territoire ou les opinions de la collectivité.

Cette méthodologie d'étude serait basée sur les modalités suivantes :

1) Localisation d'un cas (ou deux) illustrant les problèmes typiques de la zone méditerranéenne. Les cas choisis devraient être en condition de nous permettre de considérer encore la possibilité d'une intervention correcte.
2) Organisation de données sur le cas considéré et examiné à partir de différents points de vue.
3) Formulation de trois projets-stratégies d'intervention sur le même cas en vue d'obtenir :
   a) une conservation maximale de l'environnement
   b) un développement économique maximal
   c) un développement compatible avec la sauvegarde de l'environnement

Les trois projets-stratégies devraient être évalués par un groupe mixte qui devra souligner surtout :

les possibilités économiques et de ressources
les réactions sociales
les effets sur l'environnement
les transformations du paysage
les conditions de gestion, etc...

Identification et classification des typologies et des techniques d'interventions dans les processus de transformation contrôlée des zones côtières

Pour ce qui concerne les interventions technologiques de protection et de défense des côtes (oeuvres, éléments techniques, rangements physiques et aménagements, etc...), nous distinguons, sur la base de la qualité, des objectifs et des transformations apportées, entre interventions naturelles, artificielles et mixtes.

Les interventions naturelles comprennent :

- les opérations de conservation des dunes
- les opérations de réaménagement pur des plages
- les opérations d'excavation des bassins, des ports et de by-passing

Les interventions artificielles ou mixtes sont classifiées par rapport à leur fonction de protection ou de leur impact sur l'environnement.

Protections passives ou rigides :
- opération de stabilisation des lignes des rives : parois de sécurité, revêtements, murs de berge.

Protections actives ou souples :
- opérations d'élargissement des plages qui, à leur tour, peuvent être classées en deux catégories : structures de protection parallèles ou longitudinales (barrières foraines ou submergées) et structures de protection transversales (épis).
- plages artificielles ou de protection, réaménagements contrôlés avec l'intégration de barres et d'épis.

Une autre catégorie d'opérations comprend les structures de protection des ports et des canaux d'accès qui demandent à cause de leur complexité une articulation spécifique. La classification proposée range les différentes classes d'intervention sur la base des objectifs spécifiques (par exemple protection des lignes de rive); cette classification prévoit aussi une sous-classification qui correspond aux résultats des transformations en termes de prédominance sur les éléments naturels de l'environnement côtier (par exemple remodelage des lignes de rive, limitation des apports de sédiments) et spécifie aussi les unités technologiques et les éléments techniques nécessaires pour atteindre les buts prévus par l'intervention. A fins d'explication, le tableau suivant de classification et d'articulation des interventions qui modifient l'équilibre dynamique des lignes de rive est proposé.

TABLEAU 1 : MODIFICATION DE L'ETAT D'EQUILIBRE DYNAMIQUE DES LIGNES DE COTES ET LACUSTRES

CLASSE INTERVENTION	SOUS-CLASSE INTERVENTION	CLASSE D'UNITE TECHNOLOGIQUE	UNITE TECHNOLOGIQUE	CLASSE DES ELEMENTS TECHNIQUES
41.1 Protection de la ligne de rive	4.1.1 Remodelage des lignes de rive	4.1.1.A Systèmes d'excavation	4.1.1.A.a Dragage	
		Systèmes parallèles de protection	4.1.1.B.a Barrières littorales foraines	Nucléus ou corps Revêtement Couche filtre Amortissement
			4.1.1.B.b. Barrières submergées	Nucléus ou corps Protection des berges Amortissement
		4.1.1.C Systèmes transversaux de protection	4.1.1.C.a Epis	
	4.1.2. Limitation apports de sédiments	4.1.2.A Systèmes d'excavation	4.1.2.A.a. Dragage	
		4.1.2.B Systèmes parallèles de protection	4.1.2.B.a Barrières littorales foraines	Nucléus ou corps Revêtement Couche filtre Amortissement
			4.1.2.B.b Barrières submergées	Nucléus ou corps Protection des berges Amortissement
		4.1.2.C Systèmes transversaux de protection	4.1.2.C. a Epis	
	4.1.3. Charpentage de la ligne de rive	4.1.3.A Systèmes adhérents de protection	4.1.3.A.a Murs de berge	Poteaux Parements inclinés Diaphragme continu
			4.1.3.A.b Revêtements	Harpe Parements inclinés
		4.1.3.B Systèmes parallèles de protection	4.1.3.B a Barrières littorales foraines	Nucléus ou corps Couche de revêtement Couche filtre Amortissement

(suite de la page précédente)

CLASSE INTERVENTION	SOUS-CLASSE INTERVENTION	CLASSE D'UNITE TECHNOLOGIQUE	UNITE TECHNOLOGIQUE	CLASSE DES ELEMENTS TECHNIQUES
			4.1.3.B.b Plates-formes Ile	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
		4.1.3.C Systèmes transversaux de protection	4.1.3.C a Epis	
41.2 Consolidation de la ligne de rive	4.2.1 Remodelage des lignes de rive	4.1.1.A Systèmes adhérents de protection	4.1.1.A.a Murs de berge	Poteaux Parements inclinés Diaphragme continu
			4.2.1.A.b. Revêtements	Harpe Parements inclinés
			4.2.1.A.c. Parois de sécurité	Poteaux ou Harpe Parement incliné Diaphragme continu
		4.2.1.B Systèmes d'excavation	4.2.1.B.a Dragage	
		4.2.1.C Systèmes parallèles de protection	4.2.1.1C.a Barrières littorales foraines	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
			4.2.1.C.b Barrières submergées	Nucléus ou corps Protection des berges Amortissement
		4.2.1.d Systèmes transversaux de protection	4.2.1.D.a Epis	
	4.2.2 Charpentage de la ligne de rive	4.2.2.A Systèmes adhérents de protection	4.2.2.A.a Murs de berge	Poteaux Parement incliné Diaphragme continu
		4.2.2.B Systèmes parallèles de protection	4.2.2.B.a Barrières littorales foraines	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
		4.2.2.c Systèmes transversaux	4.2.2C.a. Epis	

CLASSE INTERVENTION	SOUS-CLASSE INTERVENTION	CLASSE D'UNITE TECHNOLOGIQUE	UNITE TECHNOLOGIQUE	CLASSE DES ELEMENTS TECHNIQUES
41.3 Protection de l'arrière plage	4.3.1 Charpentage des lignes de rive	4.3.1.A Systèmes adhérents de protection	4.3.1A.a Murs de berge	Poteaux Parement inclinés Diaphragme continu
			4.3.1.A.b Revêtements	Harpe Parement incliné
			4.3.1.A.c Parois de sécurité	Poteaux ou harpe Parement incliné Diaphragme continu
		4.3.1.B Systèmes parallèles de protection	4.3.1.B.a Barrières littorales foraines	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
	4.3.2 Charpentage de la plage	4.3.2.A Systèmes de conservation des dunes	4.3.2.A.a Consolidation	
4.4 Elargissement de la plage	4.4.1 Charpentage de la ligne de rive	4.4.1.A Systèmes adhérents de protection	4.4.1A.a Murs de berge	Poteaux Parement incliné Diaphragme continu
			4.4.1A.b Revêtements	Harpe Parement incliné incliné
			4.4.1.A.c Parois de sécurité	Poteaux ou harpe Parement incliné Diaphragme continu
		4.4.1.B Systèmes parallèles de protection	4.4.1.B.a Barrières littorales foraines	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
			4.4.1.B.b. Plates-formes île	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
			4.4.1.B.c. Barrières submergées	Nucléus ou corps Protection des berges Amortissement
		4.4.1.C Systèmes transversaux de protection	4.4.1.C. Epis	

(suite de la page précédente)

CLASSE INTERVENTION	SOUS-CLASSE INTERVENTION	CLASSE D'UNITE TECHNOLOGIQUE	UNITE TECHNOLOGIQUE	CLASSE DES ELEMENTS TECHNIQUES
	4.4.2. Charpentage de la plage	4.4.2.A Systèmes de conservations des dunes	4.4.2.A Consolidation	
		4.4.2.B Systèmes de réhabilitation des plages	4.4.2.B.a Réaménagement pur	
			4.4.2.B.b Réaménagement forçé	
4.4 Elargissement de la plage	4.4.3 Limitation de la ligne de rive	4.4.3.A Systèmes parallèles de protection	4.4.3.A.a Barrières littorales foraines	Nucléus ou corps Couche de revêtement Couche filtre Amortissement
		4.4.3.B Systèmes transversaux de protection	4.4.3.B.a Epis	
		4.4.3.C Systèmes de protection adhérente	4.4.3.C.a Murs de berge	Poteaux Parement incliné Diaphragme continu
	4.4.4. Dépôt de matériels inertes	4.4.4. A Systèmes de des plages	4.4.4. A.a Réaménagement pur 4.4.4.A.b Réaménagement forcé	
	4.4.5. Limitation des sédiments	4.4.5.A Systèmes transversaux de protection	4.4.4.C.a Epis	
4.5 Protection d'un miroir d'eau	4.5.1. Limitation des sédiments et des tempêtes	4.5.1.A Systèmes protection des ports et des canaux d'accés	4.5.1.A.a. Quai sur-lames	Nucléus ou corps Couche de revêtement Couche filtre Protection des berges Bloc brise-lames Bloc gardien
			4.5.1.A.b. Quai sous-lames	Nucléus ou corps Couche de revêtement Couche filtre Bloc brise-lames
			4.5.1.A.c. Antémural (à l'occurrence)	Nucléus ou corps Couche de revêtement Couche filtre Amortissement

(suite de la page précédente)

CLASSE INTERVENTION	SOUS-CLASSE INTERVENTION	CLASSE D'UNITE TECHNOLOGIQUE	UNITE TECHNOLOGIQUE	CLASSE DES ELEMENTS TECHNIQUES
			4.5.1.A.d Epis concus ad-hoc	Nucléus ou corps Protection des berges Base Bloc brise-lames
			4.5.1.A.e Bassins d'amortissement	
			5.5.1.A.f Brise-lames flottantes	
		4.5.1.B Aménagement intérieur des ports	4.5.1.B.c Quais	Nucléus Base Remplissage Amortissement
			4.5.1.B.c Appontements	Harpe Nucléus Amortissement

Pour chaque technologie envisagée, l'impact sur le paysage et sur l'environnement sera analysé. Il s'agit de réduire les risques d'un choix technologique inconsidéré et incompatible, de favoriser l'acquisition d'indications et de suggestions qui peuvent faciliter la réalisation technique de l'oeuvre, avec une bonne garantie d'insertion dans le contexte en question, tout en respectant les valeurs du paysage et de l'environnement des sites.

Critères de compatibilités avec le paysage des technologies adoptées dans les activités de contrôle et de transformation des zones côtières

Objectif : Protection des côtes

Eléments techniques :

Barrières littorales foraines et submergées

Tout en considérant les difficultés de prévision sur les changements des lignes de rive, il faut commencer par la construction de petits segments avec de grands passages qui seront fermés après avoir évalué les résultats. Le recours aux variants typologiques ("T") qui élargissent les zones de passage et l'utilisation de matériels à nature minéralogique appropriée au site, en favorisent la compatibilité environnementale.

Plates-formes flottantes

Il est possible, après avoir bâti le système de protection, d'influencer dans une certaine mesure le régime des courants, en réglant la consistance de la ligne de sable qui unit l'île à la plage. En vue de la compatibilité avec le paysage on a expérimenté des plates-formes d'îles submergées, dont les fonctions sont semblables à celles des plates-formes flottantes mais qui n'affectent pas le paysage, doivent être expérimentées.

Structures spéciales de protection

L'utilisation de structures submergées au lieu de structures flottantes favorise la compatibilité environnementale en éliminant tout impact visuel dû à l'émersion des structures flottantes.

Réaménagement et by-passing

La définition préventive des caractéristiques géométriques du projet et la connaissance de l'aspect de la plage sous l'action des ondes, l'utilisation de sable de nature minéralogique, avec une granulométrie et une couleur pareilles au sable d'origine, permettra dans le cas du réaménagement, la formation de plages artificielles non discontinues, qui ne se heurtent pas aux caractères morphologiques et du paysage du site.

Structures adhérentes

Réalisation de l'oeuvre par l'utilisation de parements inclinés au lieu de parements verticaux et avec des matériels et des "desseins" très naturels. Adoption possible de techniques de bio-ingénierie.

Epis

- Conception de systèmes d'épis avec angle variable, de façon à réduire au minimum les phénomènes d'érosion de la plage en aval ;

- Réalisation de plages alvéolaires qui laissent la vue sur la mer ;

- Utilisation de matériels naturels avec caractéristiques pareilles aux caractéristiques du site

Protection des ports, des canaux d'accès et protection contre l'envasement

Le problème de l'impossibilité de voir la mer de la terre peut être résolu seulement en mettant en valeur les parties et les éléments existant qui sont déjà consolidés sur la côte. Tout en évitant l'utilisation de sable dragué à l'intérieur du bassin du port, il est possible de limiter partiellement le "dommage esthétique" dû aux eaux troublées.

Formation et consolidation des dunes

Choix d'attente de l'aménagement des éléments

D'autres hypothèses, approfondissements et développements sont possibles aussi bien en se référant aux caractéristiques typomorphologiques et technico-constructives des technologies qu'en relation avec l'analyse / évaluation de l'impact de ces éléments sur les conditions du site. Cet engagement demande un élargissement et une finalisation différents de la recherche et une disponibilité financière plus grande.

La Communauté Européenne pourrait être l'élément de collecte et diffusion de la recherche dans ce secteur, assurant la diffusion des résultats parmi les groupes travaillant sur des objectifs similaires, et veillant au renforcement des règles européennes sur l'environnement.

Techniques de bio-ingénierie

Epis

- Conception des systèmes d'épis avec angle variable, de façon à réduire au minimum les phénomènes d'érosion de la digue en aval ;

- Réalisation de digues submersibles qui laissent la vue sur la mer ;

- Utilisation de matériaux naturels avec caractéristiques pareilles aux caractéristiques du site.

Protection des ports, des canaux d'accès et protection contre l'envasement

Le problème de l'impossibilité d'éviter l'usage de la terre peut être résolu seulement en mettant en valeur les études et les expériences existantes qui sont déjà conduites sur la côte, et qui en évitant l'utilisation de digues et l'intérêt du trafic du port, il est possible de limiter particulièrement le "dommage esthétique" dû aux ports trop larges.

Formation et consolidation des dunes

Choix et mise en œuvre de l'enherbement des dunes

Dans la synthèse, il apparaît que de nombreux développements sont possibles, aussi bien en se référant aux caractéristiques techniques appliquées et le génie-civil et les technologies qu'en relation avec l'analyse / évaluation de l'impact et des éléments sur les conditions du site. Cet aménagement demande un élargissement et une adaptation différents de la recherche et une disponibilité financière plus grande.

La Communauté Européenne pourrait être l'élément de soutien et diffusion de la recherche dans ce secteur, assurant la diffusion des résultats parmi les groupes travaillant sur des secteurs similaires, et veillant au renforcement des études interférences sur l'environnement.

Assessment of pollution abatement technologies

by Vincenzo NASO and Massimo TRONCI

Università degli Studi di Roma "La Sapienza" Dipart. di Meccanica e Aeronautica, Via Eudossiana 18, 00184 Roma, Italia

1 - TECHNOLOGIES AND ENGINEERING FOR THE ENVIRONMENT

Sustainable development within Mediterranean Countries will depend to a large extent on the capacity to minimize environmental damage. This goal requires efforts in two directions:

- *elaboration of reliable, fast and economic methods for the monitoring and surveillance of the environment and design of appropriate equipment for their realisation;*
- *development of advanced techniques and systems to protect and rehabilitate the environment.*

The future European Environment Agency has to create a special Section to coordinate every research, policy, programme, action and intervention in the field of Mediterranean environment.

Special attention has to be paid in implementing research in this area, especially with regard to the first item.

1.1 - Assessment of environmental quality and monitoring

The assessment of environmental quality and monitoring needs a wide spectrum of topics to be developed. The most important can be summarized as follows:

- *development of measurement techniques for airborne platforms* in order to develop new instrumentation for the measurement of gases and aerosol components of importance for tropospheric chemistry and to test sampling techniques suitable for the use on airborne platforms;
- *methods and instruments for measuring stratospheric constituents* (ground based measurements, airborne measurements, spaceborne measurements) such as the following molecules: ClO BrO, N_2O_5, OH and H_2O;
- *design of an"Outdoor" Smog Chamber*, using natural solar radiation to study the formation of photochemical oxidants from their precursors and, in particular, from the use of diesel and alternative fuels and to develop and test suitable models for the practical application of results;
- *analysis and fate of organic pollutants in water* aiming at developing analytical techniques for a restricted number of important pesticides (such as chlormequat and trichloroacetic acid and their degradation products) and to investigate the behaviour of pesticides during water treatment;
- *development of biosensors* for:
  - those environmental measurement problems where these offer a clear advantage in terms of sensitivity, selectivity, response time and cost compared to physical/chemical methods; and/or where continuous in situ measurements are required;
  - the measurement of toxicological effects of complex mixtures of environmental pollutants;
  - *development of laser remote sensing systems for air and water pollution monitoring* by using lidar and dial methods. Lidar is for Light Detection and Ranging; Dial is for Differencial Absorption Lidar. Lidar systems can be mounted on the ground or in towers; they can operate from vans or helicopters. They may be used in evaluating the spazial

distribution of a specific component within the environment by identifying the constituents of a complex target by essencially performing a spectral analysis at distance. The real time remote analysis capability of lidars will facilitate the immediate detection and location at any excessive release of pollution ever an extensive or sensitive area. Not only will this prevent intentional violation of emission-control standards, but in the event of an accidental discharge, this radarlike pollution earlywarning system could ensure a rapid shutdown of the offending source and possibly provide a real time map of the dispersing plume;

- *the application of satellite continuous monitoring techniques.*

1.2 - Technologies for protecting and rehabilitating the environment

An Environmental Action Programme in the field of technologies has to define the broad lines of a waste-management policy:

- *prevention of the production of waste;*
- *recycling and reuse of waste;*
- *safe disposal of non-recyclable residues.*

Preventing waste production is undoubtedly the first guideline for a waste management strategy; this issue has been confirmed by the Fourth Environmental Action Programme (1987-1992) which more specifically, emphasizes, the "urgent" need for "clean" technologies.

The broad family of Environmental protection technologies is comprehensive of:

- *cleaner technologies* (1);
- *recycling technologies*(2);
- *treatment and disposal of waste*(3);
- *risk assessment for and restoration of contaminated industrial sites* (4).

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(1) The concepts of *cleaner technologies* involves the development of low-emission and low-wastes technologies for selected industrial sectors (clean processes) and the improvement of processes monitoring and control. The major goal for research is a lower consumption of raw materials and energy and less emissions into the environment.

(2) *Emission abatement technologies* aim at the abatement of emissions to air and to water by end of pipe installation. Even though, in the long run, much effort should be allocated to the introduction of clean technologies with closed loop circuits, research into improved abatement technologies is necessary in order to achieve better environmental quality in the near future. Cost/benefit considerations should play an important role. Research in low-cost technologies is appropriate in addition to research into advanced technologies. As for water pollution abatement, European Community research in the past yielded the necessary knowledge for the application of improved technologies for pollution abatement at its point of industrial origin as well as for solving problems arising from industrial processes which still produce a high level of pollution. Research is currently undertaken on improved and more cost-effective technologies such as biotechnological processes for waste water treatment, development of modules to purify effluents with low pollutants concentration, and algal ponds with high efficiency in Mediterranean regions.

(3) Today household waste is a main problem because of the large amounts involved. For the time being it is not possible to predict all possible degradation processes occurring in wastes disposal sites and the respective environmental impacts. *Incineration* can provide substantial energy recovery for specific wastes, but land filling is still the ultimate waste disposal method for residues of any other treatment. Even though landfilling is a widely used method little is known about its overall environmental impacts. Two major disposal technologies have to be considered: above and underground disposal. Important problems involved in landfill technologies are *sealing techniques, land fill construction, prevention of undesired reactions and leachates*, and *monitoring of emissions from disposal sites*. Reconnaissance of abandoned or unregulated tips or derelict industrial sites within the Community requires a harmonized approach for site appraisal, risk assessment, monitoring and restoration. Research is needed in order to establish guidelines for the appplication of the most appropriate restoration techniques tailored to the individual problems. As for to the application itself, industry should be involved in demonstrative projects, for which specific Community Programmes exist (DG XI, DG XVII).

(4) Such actions must play an important role, as soil represents the ultimate receptor of air and waste pollution, of industrial contaminants and acts as a filter of pollution to ground water. Soil pollution abatement technologies raise issues such as cleaning-up abandoned waste disposal sites and contaminated industrial sites, involving technological application of e.g. extraction, biological treatment, in situ techniques. The treatment of contaminated sediments merits attention.

1.2.1 - *Cleaner technologies*

Existing conventional industrial processes have to be examined in order to identify those steps of the process which create major pollution, and to investigate possibilities where the concept of cleaner technologies could be introduced, resulting in new or modified, less polluting process steps.

This will include the examination of process modification such as:

- *changes from wet to dry processes;*
- *chemical to physical or chemical to biotechnological processes;*
- *reduction of process temperatures and/or pressures by the use of selective catalysts.*

Industrial sectors with highest priority are:

- chemical industry;
- pulp and paper industry;
- food industry;
- metal finishing industry;
- textile industry.

Topics to be developed are:

- process optimization based on numerical simulation;
- substitution of harmful or toxic substances, in particular VOCs;
- appropriate selection or precleaning of raw materials; development of closed loops in individual process steps (e.g. for process water);
- development of specific in-process purification steps;
- on-line process controll for a higher efficiency and reduced emissions;
- development of systems for early warning purposes, with a feedback to process-specific mass flow patterns. This item could include the development of suitable sensors and/or biosensors.

1.2.2 - *Recycling technologies*

It is necessary to promote cost-effective systems for recycling valuable materials from industrial processes, aimed at reducing the consumption of primary raw materials and wastes.

It is also desiderable improve sampling and separation schemes for wastes and used products for recycling of materials from selected industrial wastes. The research into product recycling has to cover the whole life cycle of the product: starting from raw material extraction, to the production processes, to the re-manufacturing of the used products, including their collection and the separation of individual components and materials.

High priority has to be given to the recycling of products and to the recycling of waste originated from industrial processes.

The main topics are:

- *recycling of plastic materials* (thermo and non thermo-plastics e.g. high quality polimer products);
- *recycling of composite materials* (e.g. electronical equipment, printed circuits, etc.);
- *recycling of solvents;*
- *recycling of household appliances, cars, etc.*

1.2.3 *Emission abatement technologies*

Improvement of existing abatement technologies should receive high priority, in particular in the area of thermal and catalytic processes for cleaning gas emissions from stationary sources (e.g. small combustion units). Where possible, in-process air purification should be further developed, while biotechnological processes are to be also taken into consideration.

In the field of water pollution special attention should be paid to the introduction of new treatment systems working on a biological basis. The treatment of municipal sewage and of industrial waste water streams have already been identified as major problem areas. Water consumption and re-use of process water should be investigated, especially in the food industry.

The approach and the reasearch tasks have to be classified referring to:

- *emissions to the atmosphere;*
- *emissions to water bodies.*

As for as emissions to the atmosphere are concerned, research will concentrate on:

- the reduction of gaseous and particulate emissions from stationary sources (e.g. small heat/or power producing units and incinerators). Nitrogen oxides, hydrocarbons and inhalable particulate matter are considered as priority pollutants;
- the improvement of catalytic end-of pipe technologies for stationary sources, with special emphasis on volatile organics and halogenated hydrocarbons originating from industrial production processes;
- the improvement of abatement technologies such as filtration and biofiltration including the development of appropriate filter regeneration techniques.

In the second case (emission to water bodies) the most important topics are:

- optimisation of flow patterns for integrated nitrogen, phosphorus and BOD removal in a cost-effective way and development of techniques for process control and monitoring, including the development of new sensors for on-line control;
- research on disinfection and storage of water for supply purposes to be used e.g. for irrigation, taking into consideration odours, nuisances and sanitary risks.

A more detailed analysis of abatement technologies aiming also at defining the state of the art is developed in chapters 4 (technologies for the reduction of emissions to atmosphere) and 5 (technologies for the reduction of emissions to water bodies) of this Report.

1.2.4 - *Treatment and disposal of wastes*

Available knowledge about on-going changes in landfill sites is unsatisfactory: mass flows and the composition of landfill gas and leachates over time are hardly known.

Main objective should be the study of the conditions for chemical/biological reactions in waste disposal sites in order to predict the environmental impacts; while the lack of knowledge on the long-term geophysical behaviour of disposal sites should be made up. Emphasis should also be placed on the preparation, the operation and the after-care of disposal sites.

The most important topics are:

- stabilisation and reduction of volume of wastes using, e.g., recycling, detoxification or destruction of toxic industrial wastes;

- identification of the most appropriate pre-treatment technologies;
- investigation, description and modelling of degradation processes inside the disposal site.

1.2.5 - ***Risk assessment for and restoration of contaminated areas***

The objective is to develop reliable, reproducible, comparable and fast techniques and practices for risk and hazard assessment and for the identification of appropriate remedial actions referring to the characteristics of various types of contaminated sites.

A multy-disciplinary approach is to be used in carring out the research in this field; the expected result is a common protocol for site appraisal and the related standards.

The knowledge of major industrial hazards is necessary for:

- *the identification of accident hazards and the assessment of their risk to the general population and the environment;*
- *the development of technologies for preventing and mitigating such accidents;*
- *the development of technologies for environmental restoration;*
- *the development and sorting regulatory activities derived from Council Directive 82/501/EEC.*

1.3 - The necessity of further investigation

What has so far been said represents a very general outline of possible technological solutions to the various aspects of pollution and environmental problems of the Mediterranean.

The present document does neither have the ambition, nor the objective, to exhaust the matter, which is very complex and only partially known in all its aspects, but it intends to present the scheme of a plan of investigation, hopefully to be carried out as the natural outcome of the current STOA Programme.

Future investigations would lead to the definition of "cause-conditions-effect" networks, or "trees", which would show not only the first order action-impact links, but whole chains of effects, of the second, third, order.

The main causes of environmental concern would be further identified and investigated, and appropriate technologies would be described in some details.

Table 1 shows an example of the type of matrix to be expected, listing type of pollutant, its main sources, typical means of transport to the sea (whether directly discharged, as by ships or from coastal settlements or plants, or carried by rivers, or by the atmosphere), possible remedies and/or abatement technologies.

Similar Tables, but much more analytical, will be prepared for each of the major problem-areas, listing all possible technical solutions to the problems.

Another very important future development is related to the spatial distribution of hazardous or polluting substances sources, as well as to the dissemination (predicted or measured) of such substances. This step is absolutely necessary, if one intends to describe - and then, find solutions for - the actual problematic state of the Mediterranean, which presents highly diversified geographical situations, and cannot be treated as a whole. Furthermore, national Goverments are still the authorities that have the power and the means for dealing with such tasks, and they must know the role their Country is playing and could play, in order to decide the proper course of action, select priorities, allocate resources, and so on.

Table 1 - Pollutant main sources, means of trasport to the sea and related abatement technology

Pollutant	Source	Max.Conc.	Transport	Abatement technologies	Notes
Nitrogenous					
Ammonia					
Nitrates	Fertilizers, Detergents		Rivers		Eutrophication
Nitrites					
Phosphates	Fertilizers, Detergents		Rivers		Eutrophication
Cyanides	Industry				
Heavy metals					
Mercury	Electrolytic industry		Air, Rivers		
Lead	Automobiles	0.1 ppm	Air, Rivers		
Chromium			Air, Rivers		
Cadmium					
Zinc		5 ppm			
Copper		0.1-0.5 ppm			
Hydrocarbons	Oil tankers-Spills		Direct		
	Oil tankers-Washing		Direct		
	Off-shore perforations		Direct		
	Pipelines		Direct		
Floating Plastics	Ships, Coastal dumps		Direct, Rivers		
Phenols	Steel, Textile,		Rivers	Discharge into municipal sewage?	
DDT (dichloro-diphenyl...)	Agriculture pesticides		Rivers		
Dichlorophenol	Agriculture pesticides		Rivers, Air	Alkaline chlorination	
Diclorobenzene	Agriculture pesticides		Rivers		
Toxaphene	Agriculture pesticides		Rivers		
Dieldrin	Agriculture pesticides		Rivers		
BHC(benzene hexacloride)	Agriculture pesticides		Rivers		
Compounds					
Acrylonitrile	Textile industry		Rivers		
PCB (Polychlorinated biphenyl	Electrical equipment		Air		Dioxin
Toxic chemicals	Spills		Direct		
Halogenated solvents			Rivers		
Nutrients	Agriculture		Rivers		Eutrophication
Organic suspended solids	Animals, Sewage		Rivers, Direct	Anaerobic lagoons	
Pathogenic microorganisms	Animals, Sewage, Medical wastes		Rivers, Direct		
Silt	Erosion, Mining		Rivers		

2 - STATE OF THE ART OF IMPLEMENTATION REGARDING THE APPLICATION OF EMISSION REDUCTION MEASURES (ERM)

2.1 - Transportation and pollution

Since the late 70s the transportation system has been one of the centers of political attention, not only because of its connections with the socio-economic system, but also, and mainly, for the energy consumption it involves.

In most recent years further reasons of concern and alarm have been added, as traffic is regarded as the principal responsible for urban air pollution.

The two concerns, energy consumption and pollution, are, of course, two sides of the same coin, and must be treated as a whole.

Undoubtedly, a long term strategy in this field must be based on the transfer of a large portion of the transportation from road to rail and to cabotage, and on the switch from private to public in the urban transportation sector. Collective transportation on rails, for instance, could achieve a reduction of the energy consumption with a factor of three, and of the pollutants emission with a factor of ten. This objective, though, involves a rather complex and expensive process, and requires a sharp attitude change, both of individuals and of governments.

The actions to be started require huge investments, and will provide results only after many years, but that does not mean that it is impossible to do something in the short term.

First of all it is necessary and possible to implement all solutions to fluidify and optimize the traffic, especially in urban areas. As far as pollution is concerned, fuels can be improved, as well as engines efficiency. It has to be remembered that a good fraction of present pollution is due to unefficient combustion engines, which emit unburned particles. Very important is also the maintenance of engines, and devices to trap gasoline vapours.

More stringent controls over gas emissions can be enforced.

The main pollutants produced by internal combustion engines are:

- volatile hydrocarbons, generated by an incomplete combustion; they include toxic substances, such as poly-aromatic hydrocarbons and aldeides;
- nitrogen oxides (NOx), whose formation depends on the values of many parameters, such as: combustion temperature, pressure, air excess;
- carbon oxide, also generated by incomplete combustion, that can be eliminated through appropriate air-to-fuel ratios;
- particles, composed of solids that absorb aliphatic and aromatic hydrocarbons;
- other substances, such as lead in the case of gasoline, and sulphur dioxide in the case of diesel.

Generally speaking, the emissions listed above can be limited through:

- *clean fuels, especially with regard to sulphur and lead;*
- *improvements and maintenance of engines;*
- *devices to treat exhaust gases (cathalytic mufflers);*
- *innovative combustion techniques:*

Presently, devices to treat exhaust gases seem the most efficient solution, even if some Japanese and US engines are already able to meet low emission standards without cathalytic mufflers. It can be stated that "clean engines" are the most likely future answer to the problem.

At any rate, only a common and integrated effort by all governments, based on stringent regulations for cars and fuels manufacturers, as well as for users, will have a significant impact.

2.2 - Industrial atmospheric emissions

With reference to the type of source, there are:

- *concentrated sources;*
- *diffuse sources.*

The industrial sector together with electricity production and primary to secondary energy conversion, deal mainly with concentrated sources. This type of sources is very important (even though diffuse ones are responsible to a greater extent for atmospheric pollution), because they usually produce highest pollution levels at a small scale and, on the other hand, allow greater possibilities of intervention.

This is particularly true in perspective, as many factors seem to push in the direction of even greater concentration of production in limited, restricted areas, that can be seen as veritable "pollution centers".

Another possible classification of industrial atmospheric emissione can be the following:

- *combustion emissions;*
- *process emissions.*

Combustion emissions are responsible for the emission of the "big five":

- sulphur oxides: SO_2 and, to a lesser extent, SO_3;
- nitrogen oxides: NO_2 and NO;
- carbon monoxide, CO;
- organic volatile compounds: mainly hydrocarbons;
- particles, or suspended dusts.

These are the substances most responsible for environmental degradations, including chemical alterations. CO2, being part of the natural carbon cycle, is not listed as a pollutant, even though it greatly contributes to second level environmental impacts, such as the greenhouse effet, acid rains, smog, and others.

Process emissions consist of many chemicals resulting from the various production processes: organic and inorganic gases, vapours and suspended particles.

In the USA and in Germany, several hundreds of substances are the object of regulations and controls. The European Project CORINAIR is investigating the matter.

At present is not possible to assess in quantitative terms such emissions. The most important sectors are:

- *metallurgy*
- *glass production*
- *cement production*
- *chemical industry*
- *oil refineries, petro-chemical and plastics industries*
- *wood and pulp industries*
- *rubber production*
- *tanneries*
- *food production*

Chemical industries produce gases and vapours (mostly sulphur and nitrogen oxides) from combustion processes, but also by-products of fertilizers and detergents production processes. Some of the products are hazardous or toxic: halogens, heavy metals, hydrocarbons. Besides, existing abatement systems are often rather inefficient.

Metallurgical industries emit SO_2 (from coal), NOx (form combustion), CO and CO_2 (steel production). There are also emissions of mineral and metallic particles.

Food and agricultural industry pollutes more water than air. Atmospheric pollution is difficult to assess, due to the large number and wide distribution of the sources.

Also wood and pulp industry's atmospheric emissions (hydrogen sulfide, sulfur dioxide, dust) are of secondary importance with respect to water emissions, even if in some instances very critical peak emissions (reduced sulfur, sulfur dioxide, particles) have been monitored.

Tanniers' emissions (hydrogen sulfide, solvents) though quantitatively not relevant, cause serious air pollution, also in terms of smell.

Cement manufacturing is responsible for emissions of alkaline particles produced in the ovens pre-heating phase; other emissions are metals from the clinker phase, as well as Fluorides, chlorine gas, and phosphorus.

2.3 - Political and technological answers to atmospheric pollution

In Italy, an Act of the Ministry of Environment, passed in 1990 to implement EEC regulations, adopts the concept of "best available technology". The problem is, which is the "best" technology? Who has tested it? Who owns it? Who pays for it? It is necessary to define, in legal terms, how to relate the potential air purity level to the technical means available.

In Germany, the technical level is defined as the procedures, equipment and methods that guarantee a reduction of the pollution, thus implying their having been tested.

In Sweden the concept of "best possible mean" is adopted, meaning that regulations can be enforced only if they are economically, as well as technically, feasible.

Generally speaking, it is basically useless to try to prevent pollution setting limits for each source: it is always possible that, in particular conditions, the global pollution within an area exceeds the acceptable limits, even though the single sources do not exceed their own emission limits. On the other hand, it would not be acceptable to lower the limits to technically unfeasible or economically unbearable values to take into account such possibility.

A possible solution could be the institution of a Basin Authority, responsible for a given area "at risk", provided with very broad legal, technical and financial powers.

There should also be some international coordination bodies, such as an "Air Agency", able to compensate for the different expenses met by industries located in "risky" areas.

It shoul be remembered that some abatement technologies that looked very promising on paper, have been very disappointing in the real world. Environmental technologies are quite young, and experimentation has been too short to be conclusive.

It is very important that research and demonstration programs be funded and carried out, for instance at the EEC level.

2.4 - Abatement technologies

A radical solution of the air pollution problems can only result from an integrated mix of several approaches:

- *improved fuels;*
- *combustion optimization;*
- *exhaust gases treatment.*

Fuel improvements can significantly reduce SOx emissions, while practically do not affect NOx emissions.

Through combustion optimization it is possible to reduce NOx emissions up to 50-60%; in order to reduce SOx, adsorbents are required.

There are a number of factors to be considered prior to selecting a particular piece of air pollution hardware. In general, they can be grouped into three categories: environmental, engineering, and economics. The final choice in equipment selection is usually dictated by that quipment capable of achieving compliance with regulatory codes at the lowest uniform annual cost. In order to compare specific control equiment alternatives, knowledge of the particular application and site is necessary.

The basic types of emission control devices are mechanical collectors, wet scrubbers, baghouses, electrostatic precipitators, combustion systems, condensers, absorbers, and adsorbers. All of these have been used to some extent to control emissions from a variety of processes.

A generalized design review procedure for air pollution control equipment is presented in Figure 1. A preliminary screening, however, may be performed by reviewing the advantages and disadvantages of each type of air pollution control equipment, as illustrated in Tables 2 to 10.

There are four well known technologies for the control of particulates:

- *cyclones and inertial separators;*
- *wet scrubbers;*
- *electrostatic precipitators;*
- *fabric filters.*

The most widespread control technologies for gaseous pollutants are:

- *absorbers;*
- *adsorbers;*
- *condensers;*
- *incinerators (combustors).*

Exhaust gases can be treated in very different ways, depending on the type of pollutant. Table 11 shows the abatement technologies most suitable for given pollutant and process. Table 12 illustrates selection criteria.

Many technologies have been experimented, but only few of them grant the necessary mix of technical and economic performance and reliability.

Among the most significant types of plants the following can be pointed out:

- *wet systems;*
- *semi-dry systems;*
- *dry systems.*

Typical operations are:

- *dust abatement;*
- *sulphur oxides removal;*
- *nitrogen oxides removal;*
- *heavy metals and chloro-organic compounds interception.*

Other actions would be carried out, with reference to the particular process: energy production, waste incineration, and so on.

TABLE 2

Advantages and Disadvantages of Cyclone Collectors *

Advantages

1. Low cost of construction.
2. Relatively simple equipment with few maintenance problems.
3. Relatively low operating pressure drop (for degree of particulate removal obtained) in the range of approximately 2 to 6 inches water column.
4. Temperature and pressure limitations imposed only by the materials of construction used.
5. Dry collection and disposal.
6. Relatively small space requirements.

Disadvantages

1. Relatively low overall particulate collection efficiencies, especially on particulates below 10 μm in size.
2. Inability to handle tacky materials.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 3

Adcantage and Disadvantages of Wet Scrubbers *

Advantages

1. No secondary dust sources.
2. Relatively small space requirements.
3. Ability to collect gases as well as particulates (especially "sticky" ones).
4. Ability to handle high-temperature, high-humidity gas streams.
5. Low capital cost (if wastewater treatment system is not required).
6. For some processes, the gas stream is already at high pressures (so pressure drop considerations may not be significant).
7. Ability to achieve high collection efficiencies on fine particulates (however, at the expense of pressure drop).

Disadvantages

1. May create water disposal problem.
2. Product is collected wet.
3. Corrosion problems are more severe than with dry systems.
4. Steam plume opacity and/or droplet entrainment may be objectionable.
5. Pressure drop and horsepower requirements may be high.
6. Solids buildup at the wet-dry interface may be a problem.
7. Relatively high maintenance costs.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 4

Advantages and Disadvantages of Electrostatic Precipitators *

Advantages

1. Extremely high particulate (coarse and fine) collection efficiencies can be attained (at a relatively low expenditure of energy).
2. Dry collection and disposal.
3. Low pressure drop (typically less than 0.5 inch water column).
4. Designed for continuous operation with minimum maintenance requirements.
5. Relatively low operating costs.
6. Capable of operation under high pressure (to 150 psi) or vacuum conditions.
7. Capable of operation at high temperatures (to 1300°F).
8. Relatively large gas flow rates can be effectively handled.

Disadvantages

1. High capital cost.
2. Very sensitive to fluctuations in gas stream conditions (in particular, flow rates, temperatures, particulate and gas composition, and particulate loadings).
3. Certain particulates are difficult to collect due to extremely high or low resistivity characteristics.
4. Relatively large space requirements required for installation.
5. Explosion hazard when treating combustible gases and/or collecting combustible particulates.
6. Special precautions required to safeguard personnel from the high voltage.
7. Ozone is produced by the negatively charged electrode during gas ionization.
8. Relatively sophisticated maintenance personnel required.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 5

Advantages and Disavantages of Fabric Filter Systems *

Advantages

1. Extremely high collection efficiency on both coarse and fine (submicron) particulates.
2. Relatively insensitive to gas stream fluctuation. Efficiency and pressure drop are relatively unaffected by large changes in inlet dust loadings for continuously cleaned filters.
3. Filter outlet air may be recirculated within the plant in many cases (for energy conservation).
4. Collected material is recovered dry for subsequent processing or disposal.
5. No problems with liquid waste disposal, water pollution, or liquid freezing.
6. Corrosion and rusting of components are usually not problems.
7. There is no hazard of high voltage, simplifying maintenance and repair and permitting collection of flammable dusts.
8. Use of selected fibrous or granular filter aids (precoating) permits the high-efficiency collection of submicron smokes and gaseous contaminants.
9. Filter collectors are available in a large number of configurations, resulting in a range of dimensions and inlet and outlet flange locations to suit installation requirements.
10. Relatively simple operation.

Disadvantages

1. Temperatures much in excess of 550°F require special refractory mineral or metallic fabrics that are still in the developmental stage and can be very expensive.
2. Certain dusts may require fabric treatments to reduce dust seeping or, in other cases, assist in the removal of the collected dust.
3. Concentrations of some dusts in the collector (~50 g/m^3) may represent a fire or explosion hazard if a spark or flame is admitted by accident. Fabrics can burn if readily oxidizable dust is being collected.
4. Relatively high maintenance requirements (bag replacement, etc.).
5. Fabric life may be shortened at elevated temperatures and in the presence of acid or alkaline particulate or gas constituents.
6. Hygroscopic materials, condensation of moisture, or tarry adhesive components may cause crusty caking or plugging of the fabric or require special additives.
7. Replacement of fabric may require respiratory protection for maintenance personnel.
8. Medium pressure-drop requirements, typically in the range of 4 to 10 inches water column.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 6
Advantages and Disadvantages of Absorption Systems (Packed and Plate Columns)*

Advantages
1. Relatively low pressure drop.
2. Standardization in fiberglass-reinforced plastic (FRP) construction permits operation in highly corrosive atmospheres.
3. Capable of achieving relatively high mass-transfer efficiencies.
4. Increasing the height and/or type of packing or number of plates can improve mass transfer without purchasing a new piece of equipment.
5. Relatively low capital cost.
6. Relatively small space requirements.
7. Ability to collect particulates as well as gases.

Disadvantages
1. May create water (or liquid) disposal problem.
2. Product collected wet.
3. Particulates deposition may cause plugging of the bed or plates.
4. When FRP construction used, it is sensitive to temperature.
5. Relatively high maintenance costs.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 7
Comparison of Plate and Packed Columns*

Packed column
1. Lower pressure drop.
2. Simpler and cheaper to construct.
3. Preferable for liquids with high foaming tendencies.

Plate column
1. Less susceptible to plugging.
2. Less weight.
3. Less of a problem with channeling.
4. Temperature surge will result in less damage.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 8
Advantages and Disadvantages of Absorption Systems*

Advantages
1. Product recovery may be possible.
2. Excellent control and response to process changes.
3. No chemical disposal problem when pollutant (product) is recovered and returned to process.
4. Capability of systems to provide fully automatic, unattended operation.
5. Capability to remove gaseous or vapor contaminants from process streams to extremely low levels.

Disadvantages
1. Product recovery may require an exotic, expensive distillation (or extraction) scheme.
2. Adsorbent progressively deteriorates in capacity as the number of cycles increases.
3. Adsorbent regeneration requires a steam or vacuum source.
4. Relatively high capital cost.
5. Prefiltering of gas stream may be required to remove any particulate capable of plugging the adsorbent bed.
6. Cooling of the gas stream may be required to get to the usual range of operation (less than 120°F).
7. Relatively high steam requirements to desorb high-molecular-weight hydrocarbons.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 9
Advantages and Disadvantages of Combustion Systems*

Advantages
1. Simplicity of operation.
2. Capability to provide steam generation or heat recovery in other forms.
3. Capability for high destruction efficiency of organic contaminants.

Disadvantages
1. Relatively high operating costs (particularly associated with fuel requirements).
2. Potential for flashback and subsequent explosion hazard.
3. Catalyst poisoning (in the case of catalytic incineration).
4. Incomplete combustion can create potentially worse pollution problems.

*(From: A.J. Buonicore, W.T. Davis, 1992)

TABLE 10
Advantages and Disadvantages of Condensers*

Advantages
1. Pure product recovery (in the case of indirect-contact condensers).
2. Water used as the coolant in an indirect contact condenser (i.e., shell-and-tube heat exchanger) does not contact the contaminated gas stream and can be reused after cooling.

Disadvantages
1. Relatively low removal efficiency for gaseous contaminants (at concentrations typical of pollution control applications).
2. Coolant requirements may be extremely expensive.

*(From: A.J. Buonicore, W.T. Davis, 1992)

Tab. 11 - Pollutants abatement technology

Pollutant (state)	Type	Abatement system	Devices
Particulates	Dusts	Dry	Cyclones Mechanical filters Bag filters Electrostatic Precipitators
		Wet	Washing towers (Venturi type)
Liquid	Drops	Dynamic	Inertial separators Cyclones Collision inerial separators
	Sprays Aerosols	Static	Plug bag filters
Gaseous	Inorganic Acids Anydride Oxides NOx Cl_2 SO_2 Bases	West systems (Pluristage with chemical reaction)	Washing towers (with chemical reaction) Dry or wet absorption towers
	Water insolubles organics	Thermic Chemical-physical absorption Biological	Condenser absorption devices with activated carbons Catalytic or thermic combustors
	Water solubles organic	Thermic chemical-physical absorption	Washing towers (organic solvents) Biofilters Condenser absorption devices with activated carbons Catalytic or thermic combustors Washing towers Biofilters

Table 12 - POLLUTANTS ABATEMENT TECHNOLOGIES
Application Standards

DEVICES	OPERATIONAL PRINCIPLES	APPLICATION RANGE	CHARACTERISTICS
Cyclones	Solid particles are separated form gaseous flow by centrifugal force. Liquid particles are separated from gaseous flow by centrifugal force.	P.D. > 10 μ m A.E. = 80÷85%	ADVANTAGES: - Initial low costs - Easy maintenance - Suitable for low air-pressure drop - Suitable for high powders or drops concentration DISADVANTAGES: - Only for particle dimensions ≥ 5 μ m - Limited efficiency in case of low diameter of particles or drops - abrasion phenomena
Bag filters	Particles are forced into a "grid" of exact dimensions: at the beginning of the filtration process, some coarses particles, partially occluding this "grids", realise a kind of "precoat" increasing the filtration efficiency.	P.D. > 1 μ m	ADVANTAGES: - High filtration efficiency - Low costs DISAVANTAGES: - No suitable for high powder concentration (in this case an upstream insertion of a cyclone is needed) - Extensive maintenance - Humidity problems - Solid residual production - Only for low working temperature

Table 12 (continued) - POLLUTANTS ABATEMENT TECHNOLOGIES
Application Standards

DEVICES	OPERATIONAL PRINCIPLES	APPLICATION RANGE	CHARACTERISTICS
"Absolute" filters	They are used in special cases for solid particles separation from gases (e.g. to obtain sterile conditions). The operational principle is the same of the one of the bag filters.	P.D. > 0,2 μ m A.E. = 99,997% DOP test Stopped pollutants: - radioactive particles - activepharmaceutical principles - others	ADVANTAGES: - They allow a high efficiency - The efficiency is independent from particle dimensions DISADVANTAGES: - Hight costs - Prefilters needed - Humidity problems - Not regenerable
Electrostatic precipitators	When the incoming stream that contains solid particles is submitted to an electrical field, the solid particulate is electrostatically charged and moves to the side surface where powder can be removed.	P.D. ≥ (see advantages) A.E. = 90÷99% Electrical consumption: 4÷1,2 kW/m³/s Temperature: up to 600 °C Pressure: up to 10 bar	ADVANTAGES: - For P.D. ≥ 1 μ m, efficiency is independent from particle dimensions - It is possible to use these devices in a wide range of particle dimensions - It is possible to use these devices in critical conditions too DISADVANTAGES: - High investment costs - High use costs
Washing towers	Solid particles are put in contact with water in a particular device (tower). The solid particulate bulk density lean to increase and then the powder settles down.	Stopped powders within wide range of particle dimensions A.E. = 95÷99,5%	ADVANTAGES: - Easy management - Low maintenance costs - Wide range of operational conditions.

Table 12 (continued) - POLLUTANTS ABATEMENT TECHNOLOGIES
Application Standards

DEVICES	OPERATIONAL PRINCIPLES	APPLICATION RANGE	CHARACTERISTICS
Inertial separators	Flow velocity reduction	P.D. ≥ 100 μm	ADVANTAGES: - Low costs - No maintenance DISADVANTAGES: - Narrow operational range - wide device size
Collision inertial separators	Liquid particles are separated from the gaseous flow by putting an obstacle in their path.	P.D. ≥ 2÷3 μm -	ADVANTAGES: - Low costs - Narrow device size DISADVANTAGES: - They can be obstructed by particulate.
Plug bag filters	The same of the bag filters	- Sprays 100 μm < P.D.< 200 μm - Aereosols P.D. ≥ 0,01 μm	ADVANTAGES: - High efficiency
Washing towers	It is based on the water solubility of gas compounds to be removed from air flow. The washing towers are realised in a way that allows the contact between the gas to be removed and the water. In the liquor it is possible to transform the soluble compounds in other substances (such as salts, others). SPECIAL CASES Incinerator exhaust gas treatment. Upstream to the washing towers, heavy metal filtration step and a quencing step are generally needed.	Water soluble inorganic compounds (Cl_2; H_2S; HCl; SO_2; NH_4OH; etc) Incinerator exhaust gas	ADVANTAGES: - It is the only system suitable to collect these compounds - Sufficient easy management - Low maintenance costs

Table 12 (continued) - POLLUTANTS ABATEMENT TECHNOLOGIES
Application Standards

DEVICES	OPERATIONAL PRINCIPLES	APPLICATION RANGE	CHARACTERISTICS
	SPECIAL CASES (continued) NO_x Reduction. In a first step, with the help of an auxiliary oxidant, the NO_x are oxidated into NO_2. Then the NO_2 is transformed into a fertilizer salt. Recent devices allow the possibility to re-convert NO_x produced from pickling plants into HNO_3, that is re-used at the top of the same pickling plant.		
Condensers	It is based on the vapor pressure concept. The efficiency of the device depends on the boiling point of the compound to be removed. It is possible to assist the process by a vacuum condensation.	Organic compounds	ADVANTAGES: - Low costs - Narrow device dimensions. DISADVANTAGES: - Low efficiency, that does not permit the respect of regulation limits.
Adsorption device with activated carbons	This devices are based on the adsorption capacity of activated carbons. It is possible to adsorb some pollutant, that subsequently are realeased in particular conditions. The adsorption efficiency is related to the device size. The maximum pollutant quantity that it is possible to adsorb is related to the type of pollutant. These devices need periodical regenerations. Suitable instruments keep a continuous device control.	Nearly all organic compounds A.E. = 95÷98%	ADVANTAGES: - High efficiency with low pollutant concentration too - When operational conditions allow the immediate recycling of pollutants, the pay-back time ranges from 1 to 3 years. DISADVANTAGES: - Hard regeneration after 3÷5 working years needed - Continous man control needed - High initial costs

Table 12 (continued) - POLLUTANTS ABATEMENT TECHNOLOGIES
Application Standards

DEVICES	OPERATIONAL PRINCIPLES	APPLICATION RANGE	CHARACTERISTICS
Thermal burners	Gaseous pollutants are thermal oxidated in a closed combustion chamber.	Organic compounds	ADVANTAGES: - Good efficiency, related to combustion temperature, turbulence, burner type DISADVANTAGES: - Energy costs - Possible pollutants production (such as NO_x; SO_2; Sulphuric acids, etc.)
Catalytic burners	Gaseous pollutants are catalytically oxidated in a closed combustion chamber with fixed bed and ceramic catalyser.	Organic compounds with antimony, cadmium, phosphorus, zinc, lead, quicksilver, silicon, tin	ADVANTAGES: - Good efficiency, related to combustion temperature, turbulence, burner type, catalyser type. DISADVANTAGES: - High operating costs - Narrow application limits.

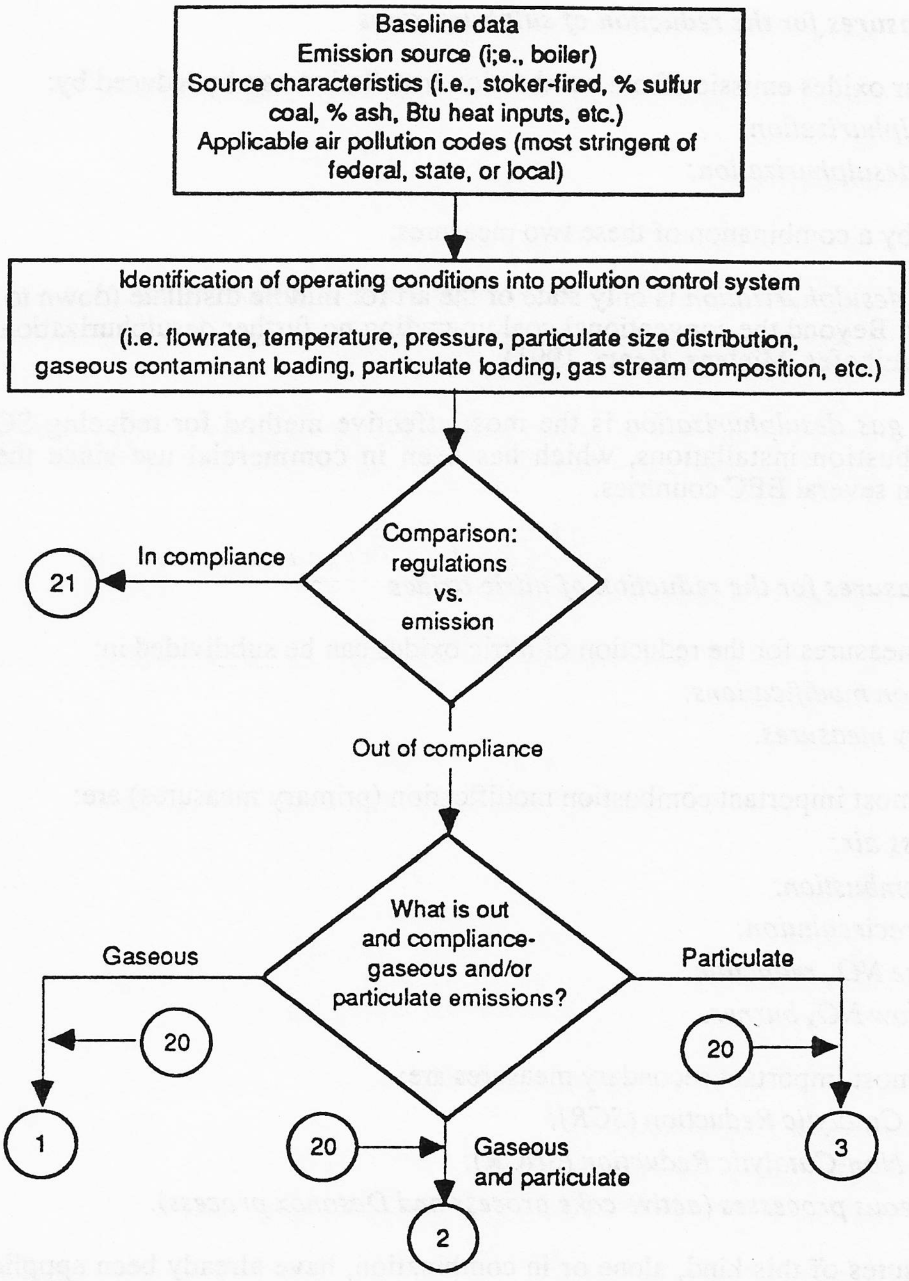


Fig. 1 - Typical generalized design review approach

As far as dust abatement technologies are concerned, it should be noted that lowering the dust emission limits from 100-150 to less than 50 mg/Nm^3, makes more and more technically and economically comparable fabric filters and electro-filters .

Looking at the economic aspects and comparing different abatement systems is very complex, depending on the following factors:

- *emission standards;*
- *plant size;*
- *fuel type and sulfur content;*
- *type of abatement technique;*
- *climatic conditions;*
- *construction standards.*

2.4.1 - *Measures for the reduction of sulphur oxides*

Sulfur oxides emission from combustion installation can be reduced by:

- *fuel desulphurization;*
- *flue gas desulphurization;*

as well as by a combination of these two measures.

Fuel desulphurization is only state of the art for middle distillate (down to 0.2% S) and natural gas. Beyond the conventional coal upgrading no further desulphurization of hard coal persues (Breihofer, Mielenz, Rentz, 1991).

Flue gas desulphurization is the most effective method for reducing SO_2 emissions from combustion installations, which has been in commercial use since the end of the seventies in several EEC countries.

2.4.2 - *Measures for the reduction of nitric oxides*

The measures for the reduction of nitric oxides can be subdivided in:

- *combustion modifications;*
- *secondary measures.*

The most important combustion modification (primary measures) are:

- *low excess air;*
- *staged combustion;*
- *flue gas recirculation;*
- *in-furnace NO_x reduction;*
- *use of a low NO_x burner.*

The most important secondary measures are:

- *Selective Catalytic Reduction (SCR);*
- *Selective Non-Catalytic Reduction (SNCR);*
- *simultaneous processes (active coke process and Desonox process).*

Measures of this kind, alone or in combination, have already been appplied in several EEC Countries since the end of the Seventies, especiallly in power plant combustion.

The application of primary measures to fulfill the emission requirements is generally insufficient. Additional measures regarding flue gas cleaning i. e. secondary measures are also necessary. The most commonly used secondary measures is the so-called Selective Catalytic Reduction (SCR).

2.4.3 - *Measures for the reduction of VOCs*

To reduce VOC emissions in various sectors both primary and secondary measures should be considered, which can be used either individually or combined.

Basically, there are two types of primary measures:

- the *substitution of VOCs* (e. g. the application of low solvent or solvent-free paints (water paints, powder paints) and glues;

- the *reduction of VOCs*, e. g. by alteration of the production method.

The VOCs reduction processes can be subdivided in:

- *oxidation of VOCs* through incineration processes (thermal incineration, regenerative thermal oxidation, catalytic incineration) and biological processes (bioscrubbers, biofilters);
- *recovery of VOCs* through absorption, adsorption, condensation and membrane process.

3 -COASTAL POLLUTION FROM CIVIL AND INDUSTRIAL WASTEWATER DISCHARGE

3.1 - Introduction

In the last years we witnessed a noteable increase of the civil and industrial wastewater discharge in the Mediterranean Sea.

On one side, the growth of the resident population in the coastal zone and the consequent extension of civil water network to supply the greater number of inhabitants and the greater average dotation of water pro-capite caused an increase of waste water discharged in the Sea.

Moreover the coastal zones are characterized by an always increasing number of tourists with consequent increasing of mass flow rates discharged in summer time, when the recreative use of coastal water is maximun. Besides the influx of tourists of different nationalities contributes to the increase of the varieties of phatogenic organisms in the sewage water.

On the other hand, the industrial activities in the coastal zone have sustained a remarkable growth with production of reflux to be discharged into the Mediterranean Sea.

From the quality point of view, the characteristics of many of these industrial discharges evolved, since new substances are introduced in the cycling processes and the composition of domestic wastes have been deeply changed due to the increasing consumption of synthetic detergents.

In conclusion the reflux, be it urban or industrial, discharged into the Mediterranean continues to increase in volume and in complexity and that brings a situation of decay in continuous evolution.

3.2 - Characterization of different contaminants in relation to Mediterranean Sea as a Receving Media

The evaluation of the effects of different pollutants poured into the Sea and the remedies to limit them would start from an exact definition of the qualitative and quantitative characteristics of the wastes, from the study of their evolution in relation to the phenomena of dilution, transportation, transformation and accumulation that takes place in the sea environment and from the precise evaluation, parameter by parameter, of the consequences on the various organisms and on the environment, taking into account the sinergic effects and the time evolution of contaminating wastes and of the environment itself.

Certainly, this kind of approach, effective also for settling the limits of acceptability of the concentrations of pollutants discharged in the Mediterranean Sea, represents, for the time being, an ideal model not only for the administrative possibility but also for the effective level of knowledge with regard to different topics.

Nevertheless, an adequate analysis of the present situation aimed at formulating possible intervention must start from the systematic evaluation of the effects that different types of pollutants have on the sea zone in connection with their capacities to receive such polluting loads.

Summing up, it is possible to subdivide the various categories of pollutants originating from civil and industrial discharges in two groups:

- The first group consists of substances that are toxic in the living organisms and in the sediments, and for which interventions are needed at the source.
- The second group consists of substances or group of substances that are generally less toxic and more easily susceptible of natural transformation that makes them less dangerous. In this case, it is not necessary to intervene at the source but to extablish limits to the maximum concentration allowed for the discharge.

The degrade of the sea water and of the coastal zones is due both to the presence of dissolved and suspended substances discharged by the natural gutters and by the sewers, and to the wastes from activities performed in the sea.

During the last years, very considerable is the sea pollution due to the oil spills. The hydrocarbons, infact, have at ambient temperature a less specific gravity than water and a low miscibility with it, so they float forming a more or less thin layer on the water surface.

This layer precludes the natural oxygen exchange, the evaporation and the solar rays filtration. This leads to the inhibition of the photosynthetic processes planctons' growth.

Very important are the damages due to the hydrocarbons toxicity too. The hydrocarbons pollution can be caused both by oil tankers accidents and voluntary discharges.

The most evident damages are those due to the oil tankers accidents; anyway it must underlined that the most of hydrocarbons spilled every year in the sea come from voluntary spills.

Generally these are discharges of polluted ballast waters tanks washing water and used lubrificating spills. Even if these discharges often take place in the open sea far from the territorial waters, they can be considered the first responsibles for the plancton destroyment that is fundamental for the first source of food of all the ittical species.

The adoption of strict rules antipollution and the development of technical solution for limiting the discharges due to the usual operations of the oil tankers reduce the oil spillage of about three millions tons per year; anyway today, more than half a million of oil is discharged by oil tankers that don't adopt proper devices.

3.3 - Abatement technologies of the main wastewater pollutants before thir disposal in the sea

The main civil and industrial wastewater pollutants are:

- organic substances and nutrients;
- inorganic pollutants.

Such pollutants will be discussed in the following paragraphs.

3.3.1 - Organic substances and nutrients

These pollutants are present both in the civil and in the industrial wastewater. Like the substances present in the effluents of alimentary, dairy, canning, textile industries etc. concerning coastal pollution, the organic substances from domestic sewers are very important; in fact their origin is the human metabolism thus they are often accompained by a very high microorganism charge, some of which pathogenic.

In other sections of this Report the biological mechanisms are described that occur when a domestic discharge is disposed in the sea without any treatment.

The biological removal of the *organic matter (BOD)* in a treatment plant take place thanks to the microorganisms' action, that can metabolize the organic matter in aerobic or anaerobic conditions. Among the biological treatments we can distinguish:

- suspended growth biological treatments;
- attached growth biological treatments.

The most important suspended growth biological treatment is the activated sludge process. This process can achieve BOD removal efficiencies of about 90÷95%. The process design characteristics of the activated sludge are nowadays really well known.

The main attached a growth biological treatments are the following:

- *trickling filters:* are one of the first biological processes developed in the civil wastewater treatments. The modern trickling filters consist of a bed of highly permeable media to which microorganisms are attached and through which wastewater is percolated;

- *packed bed reactors:* consist of a container that is packed with a medium to which the microorganisms can become attached. Wastewater and air or pure oxigen necessary for the process are introduced from the bottom of the container;

- *rotating biological contactors:* consist of a series of closely spaced circular disks of polystyrene or polyvinyl chloride. The disks are partially submerged in wastewater and rotated;

- *fluidized bed reactors:* are reactors, still yet object of research, that consist of a container whose packing medium is expanded by the upward movement of fluid. The peculiarity is that porosity, and consequently microorganisms concentration, can be modified by controlling the flowrate of fluid.

It has to be underlined the interest of some of the attached growth reactors (packed bed reactors, fluidized bed reactors) which, thanks to the high specific surface of the packing medium, allow to obtain really higher concentration of microorganisms than the suspended growth reactors, and so a drastic reduction of the volumes of the tanks and a reduction of power consumption.

The interest of these processes is also due to their flexibility to the excursions of the organic and hydraulic loadings.

Concerning the *nutrients* (nitrogen and phosphaopous) their harmful effects on the marine environment are well known (eutrophication). The most dangerous effect occurs when high concentrations of nutrients in the seawater are flanked by particular conditions.

For the problems of eutrophy, typical of the marine regions at a very weak exchange, progress should deal with reducing the load of nutrients deriving from domestic wastes and from the industrial activities.

On the other hand, localized action should be carried out in the most critical zone of reclamation of sediments (for example reduction of organic carbonate contents in the sediments, in order to prevent the reduction of dissolved oxygen and to allow the solubilization of the contained nutrients).

Strictly related to the former are the actions to be carried out for the reduction of risks of distrophic crisis occurring in the costal areas particularly confined, like lagoons. Such actions can deal with the improvement of the hydrodynamic conditions of the interested zone, but also in a reclamation of sediments and in the removal of the quantities of macrofitic algas produced in the spring period.

The emergency actions are related to the supplying of subsidiary energy (for example by using artificial pumpings), integrative or substitutive of that supplied by the external agents, as the wind and the sea. These systems are particularly expensive and could be adopted in regions of limited extension; they also require the capability or foreseeing the evolution of environmental variables (wind, temperature and insolation).

About the abatement technologies, it is better to make a distinction between the nitrogen and phosphorous removals.

In the wastewater treatment plants, the *nitrogen removal*, is often a biological process. The process consists of two different phases: in the first phase the oxidation of the ammoniacal nitrogen occurs; in the second the reduction of the nitrates and nitrites to molecolar nitrogen occurs. The main characteristics of the reactors in which the nitrification process occurs are not so different from the characteristics of the reactors in which the biological oxidation of the carbonaceus matter occurs. In fact, often, the two processes take place in the same reactor.

On the contrary, the denitrifying microorganisms need an anoxic environment for the reduction of the oxidized nitrogen; in fact they use the oxygen bonded to the nitrogen that is so trasformed in molecolar nitrogen.

The *phosphorous removal* usually is obtained by chemical precipitation. Anyway really interesting seems the phosphorous biological removal and the possibility of modifying the existing treatment plants with the introduction of an anaerobic step, before the anoxic and aerobic steps where the BOD and nitrogen removal occurs.

The advantages of this process are both in the simpler operative conditions (there's no need of chemical additives) and in the less sludge production.

Finally it is important to underline two concepts:

- domestic wastewater disposal in the sea, even if treated and clorated, always produces a residual bacterial pollution, thus it is necessary to get the discharge point out from coast;
- the advanced levels reached by the research in the wastewater treatment field are not supported by analogous levels in the treatment plants management. In fact it would be very important to be able to make the most of the potentiality of the existing treatment plants by a correct management.

3.3.2 - Inorganic pollutants

The inorganic pollutants, mainly present in the industrial wastes, are particularly noxious for the marine environment and can be very dangerous for the human health too. When the inorganic pollutants are discharged in the civil sewer, they can completely inhibit the biological processes of the wastewater treatment plants. The main inorganic pollutants are: cianioss, heavy metals (as Cr, Ni, Pb, Cd and Ag) and pesticides.

Metals usually are present in the wastewaters as salts, but they can be present as organo-metal too. The organo-metal are particularly dangerous because in the meanwhile the organic substance is metabolized by the microorganisms, the metal accumulates in the tissue cells.

The metal so enter in the alimentary chain that, beginning from the marine microorganisms, arrives to the man.

Concerning the *metals removal*, we can distingue two cases:

- metals present in the wastewater as salts whose removal (that take place alkalizing the solution with lime or soda), is not difficult because the metal hydroxioes are insoluble and can be removed by sedimentation;
- metals present as acids, whose removal needs a reduction in an acid environment before the alkalinization.

Other operations and processes are illustrated in Table 13 with other advanged wastewater treatment.

For *pesticides* the possibility of detoxication exists for some compounds by alkalization with soda or lime at high pH. The treatment leads to the hydrolytic decomposition of biocides, generally favoured by temperature.

A number of methods are known of chemical oxidation with chlorine, chlorine dioxide, potassium permanganate, peroxides and ozone. The results obtained considerably differe from case to case. Chlorine and peroxides generally exhibit a quite poor effect. Oxidation with ozone is more effective on unsaturated compounds than on the saturated ones.

The treatments based on adsorption phenomena are among the most effective ones. For such a purpose, the use of bentonite, saturated clay, hydrous aluminium silicate, activated carbon and other substances is generally used. Activated carbon is however one the most interesting from the point of view of the possible applications. Such a treatment, if suitably dimensioned, generally allows particularly high removal levels and the achievement of low residual concentration.

Table 13 - Advanced wastewater-treatment operations and processes

DESCRIPTION	TYPE OF WASTEWATER TREATED(a)	PRINCIPAL OR MAJOR	WASTE FOR ULTIMATE USE DISPOSAL
Physical unit operations			
Air stripping or ammonia	EST	Removal of ammonia nitrogen	None
Filtration: multimedian	EST	Removal of suspended solids	Liquid and sludge
Diatomite bed	EST	Removal of suspended solids	Sludge
Microstrainers	EBT	Removal of suspended solids	Sludge
Distillation	EST nitrified + filtration	Removal of dissolved solids	Liquid
Electrodialysis	EST + filtration + carbon + adsorption	Removal of dissolved solids	Liquid
Flotation	EPT, EST	Removal of suspended solids	Sludge
Foam fractionation	EST	Removal of refractory organics, surfactants, and metals	Liquid
Freezing	EST + filtration	Removal of dissolved solids	Liquid
Gas-phase separation	EST	Removal of ammonia nitrogen	None
Land application	EPR, EST	Nitrification, denitrification removal of ammonia nitrogen and phosphorus	None
Reverse osmosis	EST + filtration	Removal of dissolved solids	Liquid
Sorption	EBT	DDIS	Liquid and sludge
Chemical unit processes			
Breakpoint chorination	EST (filtration)	Removal of ammonia nitrogen	Liquid
Carbon adsorption	EPT, EST (filtration)(b)	Removal of dissolved organics, heavy metals, and chlorine	Liquid
Chemical precipitation	EBT	Phosphorus precipitation, removal of heavy metals, removal of colloidal solids	Sludge
Chemical precipitation in activated sludge	EPT	Removal of phosphorus	Sludge
Ion exchange	EST + filtration	Removal of ammonia and nitrate nitrogen	Liquid
Electrochemical treatment	Untreated	Removal of dissolved solids	Liquid and sludge
Oxidation	EST	Removal of refractory organics	None
Biological unit processes			
Bacterial assimilation	EPT	Removal of ammonia nitrogen	Sludge
Denitrification	Agricultural return water	Nitrate reduction	None
Harvesting of algae	EBT	Removal of ammonia nitrogen	Algae
Nitrification	EPT, EBT	Ammonia oxidation	
Nitrificatio-denitrification	EPT, EBT	Total nitrogen removal	Sludge

(a) EPT = effluent from primary treatment; EBT = effluent from biological treatment; EST = effluent after secondary treatment.

(b) Optional

3.4 - The organization of the control of coastal pollution - Monitoring

The controlling Authority should carry out sampling and analysis of the effluent to ensure that the discharge is within the prescribed limits and of the seawater to confirm that the environmental quality within the defines zone meets the use requirements.

Sampling from a submerged outlet is usually impraticable. It will normally suffice if the sample is taken from the pipeline near the shore line and when installing new pipelines it should be a requirement that facilities be provided to take representative samples by the provision of a suitable access chamber. It is also desiderable that provision be made for gaugin the flow, perhaps by spot checks for small discharges but for major discharges a continuos flow recorder and integrator should be installed.

If the discharge point is outside the defined use zone the monitoring of the environmental quality will be near the boundary where the maximum concentration of the effluent will be expected. Where the outlet is situated within a use zone then the question arises of where the receiving water should be taken into consideration.

If the extreme case of no dilution were to be enforced the discharge would need to be of the same quality as the use quality of the receiving water.

If a dilution zone is permitted the sample will preasumably be taken at a specified distance or at a point on a fixed perimeter.

Within this area the environmental quality standards will not apply. The size of the zone will influence the quality of the effluent required and therefore the extend of treatment necessary.

4 - POLLUTION FROM MARITIME TRAFFIC

The Mediterranean Sea is a highly degraded environmental system, mainly as a consequence of the large population and industrial activities located along its coasts, and of the level of maritime traffic. Ships, in particular, cause pollutions in several ways. Hydrocarbons pollution is a particularly relevant problem to be assessed for the definition of a protection policy of the mediterranean maritime environment.

In the following paragraphs the reduction and prevention technologies for the hydrocarbons pollution will be analyzed.

As the potential pollution sources and mechanisms are so diversified, it is necessary to to define and to enforce a global management policy, regarding the whole area. Such policy should, on one hand, take into proper account the development needs and the commercial interests of the Mediterranean countries; on the other, promote effective environment protecion actions.

Specific actions shoul derive from the detailed analysis of each pollutant, leading to the definition of technical standards concerning the design, construction and management of ships and maritime equipment.

In this respect, and taking into account the most recent studies (see, for instance, the MARPOL Programme of the International Maritime Organisation), the following actions can be proposed:

A) Evaluation of the optimal solutions to dispose of wastes produced on and by ships:

1. optimal criteria to minimize the production of wastes onboard;
2. characterisation of wastes and methodologies for optimising their diversified collection;
3. technical-economic analysis of currently used waste disposal procedures;
4. evaluation of the effects of different technologies on safety and on crew health;
5. comparison of various disposal technologies;
6. risk assessment of onboard incineration;
7. characteristics of onboard incenerators;
8. monitoring and control methodologies for gaseous emissions produced by onboard incinerators, and technologies to reduce the consequent atmospheric pollution;
9. analysis of current control systems of waste disposal equipment;
10. evaluation models of the environmental impact of onboard incenerators;
11. technical-economic analysis of the energy recovery potential of onboard incinerators.

B) Prevention of atmospheric pollution caused by ships:

1. technical-economic analysis of the alternatives to CFC in onboard refrigeration and air conditioning systems;
2. technical-economic analysis of the alternatives to halon in onboard fire protection systems;
3. evaluation of gaseous emissions produced by onboard incenerators (see point A8);
4. study of diesel fuels currently used for naval engines, and of their atmospheric emissions;
5. analysis of quality control systems of onboard potentially polluting equipment and plants.

4.1 - Reduction and prevention technologies for the hydrocarbons pollution of the sea

Annual transportation of oil across the Mediterranean sea amounts over 300 million tons; this is about 25% of the total world oil traffic (Medugno, 1992). Transport, storage, and use of hydrocarbons in the Mediterranean area inevitably produces a large flux of pollutants toward the Sea that, although it has been decreasing constantly in the last 20 years, constitutes an heavy pollution load for the close Mediterranean basin. According to UNEP estimates (UNEP, 1988) about 635000 tons of hydrocarbons reach annually the Mediterranean Sea (see Tab. 14).

Table 14
Inputs of oil pollutants to the Mediterranean Sea (mt/year x 1000)

- From marine transportation of hydrocarbons (Operational discharge, marine terminals, etc.)	330
- From municipal wastewater and urban runoff	160
- From industrial wastewater and discharges	110
- From atmosphere	35
TOTAL	635

In addition to the diffuse hydrocarbon sources, accidental spills also significantly contribute to the total oil pollution, especially those occurring during sea transportation of petroleum products (see Tab. 15).

Table 15
Oil spills due to tanker catastrophic accidents in the Mediterranean Sea

Name of tanker	Date	Place	Quantity of Oil (mt)
Indipendentia	Nov. 1979	Bosphorus (Turkey)	94.600
Irenes Serenade	Feb. 1980	Bail Nevorino (Greece)	40.000
Juan A. Lavalleja	Dec. 1980	Arzew (Algeria)	39.000
Cavo Cambanos	Jul. 1981	Corsica (France)	18.000
Haven	Apr. 1991	Genoa (Italy)	30.000

An effective strategy against the risk of hydrocarbon pollution of the sea has to be based on preventive actions such as: reduction of sea transportation by promoting pipeline construction, renewal or substitution of older tankers, tighter environmental regulations, redefinition of oil routes avoiding sensible coastal regions. However, due to the enormous volume of oil to be shipped across the Mediterranean Sea, hydrocarbon pollution risks will always be high; for this reason much effort of R&D is presently devoted to develop efficient technologies for mitigating oil spills environmental impact.

The technologies for the reduction and prevention of the hydrocarbons pollution of the sea can be classificated as follows:

- *prevention technologies;*
- *technologies for the treatment of polluted sea and beaches.*

4.1.1 - Prevention technologies

The prevention technologies can be classified as follows:

- *L.O.T. (Load On Top):* consists in washing the tanks where the ballast will be stowed and in putting the slop in one or two tanks. So the washing water of the tanks can be discharged without any problem, while the slop will be confered to a treatment plant.
- *S.B.T. (Segregated Ballast Tanks):* consists in employing some tanks just for the ballast that can be discharged without any problem.
- *P.L. (Protective Location):* consists in positioning the ballast tanks so to prevent the oil spill if oil tanker grounds.

4.1.2 - Technologies for the treatment of polluted sea and beaches

We can distingue four different steps for the pollution reduction process:

- *Data acquisition:* consists in the identification of oil spilled, meteomarine conditions, tides, currents and the foresseeable spot movement.
- *Valutation of the situation:* after the data acquisition the risk zones must be identified together with the possible interventions.
- *Intervention choice.*
- *Pollutants collection or dispersion.*

Presently available technologies for the treatment of sea and beaches polluted by hydrocarbons can be divided into four main categories:

- *confinement of the spill by floating barriers and removal of the entrapped oil*
- *use of dispersing agents*
- *use of oil-absorbing substances*
- *use of oleophilic fertilizers aimed to speed natural biodegradation processes*

4.1.2.1 - Floating Barriers

If environmental conditions are favorable, the best option is to recover as much oil as possible from the sea surface.

The spill is confined by special floating barriers and the entrapped oil is collected by boats equipped with *skimmers* (Westermeyer, 1991; Kelso and Kendziorek, 1991). Success of this type of solution is largely dependent on the availability of specially equipped boats able to reach in short time place where the accident occurred and on favorable meteorological conditions (Kelso and Kendziorek, 1991).

Although this technology has been progressing rapidly in the last 10 years, recovery of oil from spills in the sea remains quite limited (Specchia, 1984). Recent estimates give a maximum of 20% recoverable oil in the best environmental conditions. Usually it's not possible to collect more than the 7÷10% of the oil spill.

This intervention is auspicable when the spot's thinckness is more than 2 cm. The collection is quite difficult when the sea is rough (HS = 0,50÷1,25 m) and is impossible when the sea is very rough (F = 4, HS = 1,25÷2,5 m).

The collection operation consists of two different steps:

- the spot holding;
- the oil spill recovery.

The most interesting system for holding the pollutants discharged in the sea is the buoyant boom, whose function is to delimit the spot for the next collection or to protect the coastal zones. There are three different kinds of booms relating to the marine zone where they are employed:

- calm water booms;
- harbor booms;
- off shore booms.

Skimmers are mechanical devices whose scope is the collection of the hydrocarbons discharged in the sea without the alteration of their physical characteristics. They are usually used with the booms that deviate the bouyant hydrocarbons towards the skimmers.

There are two types of skimmers:
- mechanical skimmers;
- oleophil skimmers.

In Table 16 the main characteristics of the skimmers are illustrated.

Table 16 - Main characteristics of the skimmers

TYPE OF SKIMMERS	HYDROCARBONS	LIMITING WAVES	SENSIBILITY TO WASTES	SELECTIVITY PERCENTAGE	RECOVERY RATE
DIRECT SUCTION	ALL	CALM WATER	VERY SENSIBLE	WEAK	5-200 mc/h
OVERFLOWING	ALL BUT THE VISCOSE EMULSION	f<2	VERY SENSIBLE	0-70%	1-50 mc/h
CENTRIFUG VORTEX	NOT VISCOSE	f<2	SENSIBLE	40-80%	5-700 mc/h
BELT	ALL	f<2	NOT SENSIBLE	40-90%	1-300 mc/h
OLEOFIL DRUM	ALL BUT THE VISCOSE EMULSION	f<3	SENSIBLE	50-90%	1-60 mc/h
OLEOFIL PLATES	ALL BUT THE VISCOSE EMULSION	f<3	SENSIBLE	50-90%	1-400 mc/h
OLEOFIL BELT	NOT VISCOSE	f<1	SENSIBLE	50-90%	10-300 mc/h
BUOYANT CABLE	VISCOSE	f<3	SENSIBLE	40-90%	1-50 mc/h
BOOM SKIMMERS	ALL BUT THE VISCOSE EMULSION	f<4	SENSIBLE	ACCETTABLE	100-270 mc/h

4.1.2.2 - Dispersing agents

Chemicals able to favour rapid dispersion of oil in the sea water forming a finely divided emulsion are often used to prevent the oil from reaching the coast. The dispersing action also speeds up the natural biological degradation of the hydrophobic pollutants by dividing them into very small droplets; this greatly increases the oil/water surface that it is where the microbial attack takes place (Kelso and Kendziorek, 1991; Specchia, 1984).

Although last generations of commercially available dispersing agents are much less toxic for marine plants and animals than the previously used products, many uncertainties still remain regarding their usage (Concawe, 1981; Specchia, 1984) for the following reasons:
- the practical impossibility of following the fate of pollutants once they are dispersed in the open sea;

- the greater toxicity for benthonic microorganisms of the finely divided hydrocarbons with respect to the undispersed form;
- the significant increase of the organic load to be degraded due to the added dispersing agents whose constituents are also largely made of hydrocarbons.

Current efforts of R&D for new dispersing agents aim to further reduce the toxicity on marine organisms and to establish the ultimate effectiveness of their usage (Protchard and Costa, 1991).

4.1.2.3 - Oil absorbing materials

Some materials having an high oil absorption capacity may be used for absorbing the oil floating on the water surface; because of their very low density, the absorbents can than be harvested by mechanical means.

Nowadays commercially available products have both natural - Cotton, Milkweed, Kenaf, etc. fibers - (Chol and Cloud, 1992) and synthetic origin - polypropylene, polystirene or polyurethane foam - (Kunin, 1977).

Sorbents are generally marketed as sheets, power, chips, rolls or booms and their oil sorption capacity can be up to 40 g of crude oil per g of material (Kunin, 1977).

The presence of absorbent materials in an oil spill facilitates a change of phase of the pollutants from liquid to semisolid. Once this change is achieved, the removal of the absorbed oil by mechanical methods is not difficult (Chol and Cloud, 1992).

Most oil absorbents suffer from several disadvantages:

- deficiency in ability to retain the absorbed oil;
- in spite of treatment aimed to make them water repellent, there is a decline if their oil-absorbing capacity because of water infiltration;
- although they are capable of absorbing floating oil from water surface, they are incapable of substantially absorbing water dissolvent oil;
- due to their negligible expansion during absorption their bulk density tends to increase, making more difficult handling and storage.

Current research activities are oriented to overcame these problems and to the evaluation of the absorption capacity of new polymeric matrices towards different types of oils and several organic products such as chlorinated, aromatic and paraffinic solvents (Bonfanti and Lezzi, 1993).

4.1.2.4 - Oleophilic fertilizers

The most important natural defense mechanism by which the environment face hydrocarbon pollution is biodegradation (ENEP, 1988; Atlas, 1981). Most of the oil constituents (aliphatic, aromatic, nitrogen or oxygen or sulphur containing hydrocarbons) can be degraded by specialized microorganisms. Recalcitrant compounds unable to be biodegraded are those of high molecular weight (e.g. asphaltenic compounds). These are to be considered environmentally inert (Bartha, 1986).

Pollutants biodegradation kinetic depends on many parameters (Atlas, 1981; Bartha, 1986) such as physical status and type of compounds, temperature, availability of oxygen or of other electron acceptors, nutrient availability for growth (e.g. nitrogen and phosphorous). Deficiency of nitrogen and phosphorous represents one of the main limiting factors for the biodegradation of hydrocarbons in the open sea (Olivieri et al, 1976 and 1978, Lee and Levy, 1989). For this reason specific formulations of N and P (Olivieri et al, 1976) have been studied to supply needed nutrients to the degrading populations. Main characteristics of the nutrients formulations are the low solubility in the sea water, the oleophilicity, and the high availability of the N and P constituents to the hydrocarbon oxidizing microorganisms.

Some of the oleophilic fertilizers have been thoroughly tested in open sea experiments (Olivieri et al, 1978) and their efficacy have been demonstrated with specifically developed monitoring methods (Robertiello et al, 1983); nevertheless, only recently they have been used in practical applications.

The usefulness of oleophilic fertilizers for the biological reclamation of polluted beaches and coastal waters have been shown during the environment restoration activities following the Exxon Valdes accident (Protchard and Costa, 1991).

The limits of the technology based on oleophilic fertilizers are mainly related to the slow pace with which pollutants are biologically degraded. Research efforts are directed to overcome the speed limitations, one interesting approach is based in the synergic promotion of both the hydrocarbon degradation and the oil dispersing action carried out by the biosurfactants produced during degradation.

5 - SUGGESTED STRATEGIES FOR THE PROTECTION OF THE MEDITERRANEAN MARITIME ENVIRONMENT

The analysis of different types of pollution that modify the quality of sea water also suggests possible strategies.

To reduce the impact on marine environment of the diffusion in sea of pathogenic microrganisms from domestic waste, the most adeguate remedy is joining the treatment of disinfection with the dilution capacity and self depuration of the marine environment.

In other words, one must look for the optimum combination between the length of the discharging pipeline to the sea (allowing to reach zones with highest capacity of dilution) and efficiency of the system of treatment on land. The solution has to be found taking also into account the costs for the construction and management as well as the rate of confidence of the combined system treatment-outfall.

As for the remedies for pollution by oil, we must distinguish between the prevention of spilling and the action to be carried out once the accident occurred.

The preventive remedies mainly consist in the reduction of risks of spilling in regions characterized by high environmental vulnerability. Such remedies may deal with the indentification of the shortest routes of petrol tankers avoiding to cross areas that, due to the direction of prevailing winds and the environmental characteristics, can undergo irreparable damages by an accidental spilling.

In such sense, we have to support legislative activity with an adeguate capacity of better understanding and also of simulating (physic, mathematics, or hybride) the behaviour (local or on extensive areas) of the Mediterranean Sea and its reactions to any possible shock.

A second preventive remedy deals with the state of efficiency of the oil tankers in relation to their age, state of maintenance and efficiency of controls by the Authorities.

The most effective technical solutions deal with the doubling of the shell or the division of the internal volumes into compartments, so limiting the quantity released in case of leakage produced by an accident.

The remedies for emergencies must be thought in relation to the necessity of a rigid intervention and to the reduction of volumes of petrol spilled. A control system of the entire marine traffic, together with an alarm unit for immediate intervention looks necessary.

Any reduction of volume spilled and of any other negative effect consists both in systems suitable for limitating the areas interested by the spreading, and in systems for increasing the rapidity of degradation of petrol.

In general, this type of intervention deal with the direct application of substances and technologies capable of generating physical or chemical phenomena acting on the destiny of petrol spilled and on its effects on flora and fauna.

Any progress in this field is evidently linked to the increase of efficiency of the products and the employed technologies. A strong support to the specialized operators has to be supplied, in the areas of theoretical research and the of validation of the obtained results.

As for the problems of eutrophy, typical of the marine regions at a very weak exchange, progress should deal with reducing the load of nutrients deriving from domestic wastes and from the industrial activities.

On the other hand, localized action should be carried out in the most critical zone of reclamation of sediments (for example, the reduction of organic carbonate contents in the sediments, in order to prevent the diminution of dissolved oxygen and to consent the solubilization of the contained nutrients).

Strictly related to the former, are the actions to be carried out for the reduction of risks of distrophic crisis occurring in the coastal areas particularly confined, like the lagoons.

Such actions can deal with the improvement of the hydrodynamic conditions of the interested zone, but also in a reclamation of sediments and in the removal of the quantities of macrofitic algas produced in the spring period.

The emergency actions are related to the supplying of subsidiary energy (for example, by using artificial pumping), integrative or substitutive of that supplied by the external agents, the wind and the sea. These are particularly expensive systems and could be adopted in regions of limited extension; they also require the capability of foreseeing the evolution of environmental variables (wind, temperature and insolation).

In other words, the formation mechanism of the phenomena and the particular technical and economical difficulties of any kind of curative action implies that one must get over a crisis with peculiar and well located activities.This can only be obtained by putting an adeguate set of simulation models in order not only to prevent, as much as possible, the extension of crisis conditions in extensive areas but also to individuate the zones in which the interventions can achieve adeguate effects. As a matter of fact, one must also consider, as we pointed out in our theoretical description of phenomena, that an extensive area in distrophic crisis can depend on a small limited areas of formation of the crisis, in which the local result extends naturally to a greater level.

Potential applications of remote sensing techniques for monitoring marine pollution events in the Mediterranean Sea

by Werner ALPERS

Universität Hamburg, Institut für Meereskunde, Troplowitzstr. 7, 2000 Hamburg 54, Germany

I. INTRODUCTION

The Mediterranean is one of the most polluted seas of the world. This is due to the fact that it is a semi-enclosed sea with large inputs of pollutants from rivers, ships, and the atmosphere, but with little water exchange with the open ocean through the Strait of Gibraltar.

There are various pollutants discharged into the Mediterranean - mineral oil, heavy metals, pesticides and other man-made chemicals. Thus, around the north-west corner of the Mediterranean alone (Spain, France, Italy), there are well over 50,000 industrial enterprises discharging their effluents to the sea. It has been estimated that the organic load of industrial waste in that area is equal to that of domestic sewage of some 25 million people.

In 1972 it was estimated that the total amount of mineral oil released into the Mediterranean was 300,000 tons. At present estimates vary greatly, going as high as 1,200,000 tons, although the Mediterranean has been declared "a special area" - where deliberate petroleum discharges from ships are prevented - by the MARPOL Convention. There is ample evidence of repeated, numerous, offences against the MARPOL Convention as seen on radar images of the Mediterranean by the First European Remote Sensing Satellite ERS-1 (see below).

Heavy metals, in particular mercury, cadmium, lead, copper, zinc and selenium which are discharged into the sea as industrial waste products, have been identified as particularly harmful to marine life. Unfortunately, at present there seems to exist no proven remote sensing technique by which these metals can be sensed from airplanes or satellites: the electromagnetic wavelengths used for remote sensors exclude the possibility of a direct classification of metal ions. One can only envisage indirect measurements, such as the detection (and possibly classification) of complexes consisting of organic substances / heavy metals and/or metal-organic compounds. Much effort will have to be spent, however, in order to verify this potential application.

Many pesticides, in particular aromatic compounds, basically can be investigated by the lectromagnetic wavelengths used for remote sensors. At present, however, discrimination remains very difficult because many biogenic compounds in the bulk water will show absorptions of the electromagnetic signals in the same frequency range. Yet potential applications can be envisaged during accidents, if larger amounts of pesticides are released into the sea, at concentrations well above the background level of other organics.

In general, the chances for detecting and classifying organic pollutants will vary greatly, acording to the absorption frequency of their respective compounds. It is vital to improve the resolution of the frequency bands of sensors to minimize potential bias effects by other organics. Presently at best "classes of compounds" can be discriminated if high concentrations are present.

The distribution of chlorophyll - and therefore algal blooms - in the sea can be determined by multi-spectral colour scanners, imaging spectrometers, and lidars operating in the visible and ultraviolet spectral band. In this case, since excessive algal blooms are related to an increase of inflow of nutrients into the sea, remote sensing techniques can provide indirect information on effluents from rivers, on the transport of coastal pollutants and on the ecological condition of a marine environment.

As emphasized at the 1987 EEC Oldenburg International Colloquium on Remote Sensing of Pollution of the Sea, remote sensing techniques are most powerful in detecting organic substances floating on the sea surface (Hühnerfuss and Alpers, 1987). In this report we concentrate our discussion mainly on remote sensing techniques for detecting mineral oil spills at sea, drawing largely on the findings and recent experience gathered since the pioneering ARCHIMEDES I & II Experiments run in the previous decade by the Commission of the European Communities.

II- INSTRUMENTS

The following sensors offer the greatest potential for detection of marine pollution:

A - Imaging radar - either real or synthetic aperture radar
B - Multi-frequency microwave scatterometer
C - Microwave radiometer
D - Multi-spectral scanner and imaging spectrometer operating in the infrared, visible, and ultraviolet
E - Fluorescence lidar
F - Optical sensors (camera, low-light TV, human eye)

A - Imaging Radars

Imaging radars are well suited for the detection of mineral oil discharged from ships, and of oily substances released into the sea from industrial and sewage plants. They usually float on the sea surface where they form large surface films or slicks. The slicks become visible on radar images because they reduce the short-scale roughness of the sea surface which determines the strength of the radar echo or the backscattered radar power. The detection requires a minimum wind speed of about 2-3 m/s for generating short ripple waves. Otherwise there would be no radar backscattering from the sea surface at oblique incidence angles. On the other hand, at very high wind speeds (typically above 15 m/s) the oil is washed down by the waves and the spill disappears from the surface, thus making it impossible to identify oil slicks on the radar image.

If the above requirements are met, oil slicks appear on the radar images as dark patches in a bright background. However, dark patches can also originate from natural surface films floating on the sea surface which are produced by plankton or fish, as well as from a local reduction of the wind speed, i.e., in the wind shadow of an island. But for an experienced analyzer it is often possible to distinguish between these different phenomena causing a reduction of the sea surface roughness by their location and the geometrical form of the patch. In particular, freshly spilled mineral oil can easily be identified on radar images by the form of the patch. It is not known for how long mineral oil spills maintain their characteristic shape. This will depend on wind, wave, and current conditions. The geometric form will also change with time. It is estimated that typical times after which mineral oil spills still can be identified by their shape are several hours (in some cases it may be even several days). Later their shape becomes diffuse, and it is no longer possible to distinguish them from natural surface films.

Natural monomolecular surface films are frequently encountered in the Mediterranean, especially in coastal areas during summer and autumn. ERS-1 SAR imagery acquired over the Mediterranean often shows large black patches which are believed to be caused by natural slicks.

Radar images acquired from satellites can be very useful for gathering statistical information on oil discharges from ships. Thus, on a series of five radar images acquired by the First European Remote Sensing Satellite, ERS-1, on Aug. 26, 1992 (orbit 5820, frames 2907, 2925, 2943, 2961, and 2979, 08:27 UTC), over the Mediterranean between Port Saïd and Cyprus more than 20 mineral oil spills can be delineated in a 100 km wide swath. The longest oil spill has a length of about 20 km and the largest one covers an area of 8.4 km^2. Another ERS-1 SAR acquired on Oct. 3, 1992 (orbit 6364, frame 2961, 08:34 UTC), over the same area shows in an area of 100 km x 100 km five major spills, the two largest ones cover an area of 21.8 km^2 and 17.5 km^2. Another example is an ERS-1 SAR of the sea area surrounding the Liparian islands acquired on Aug. 23, 1992 (orbit 5785, frame 765, 21:16 UTC), showing an oil spill which is approximately 25 km long.

The longest oil spill detected so far on an ERS-1 SAR image has a length of more than 100 km (orbit 6466, frames 2889 and 2907, acquired on Oct. 10, 1992, at 11:34 UTC over the North Atlantic near the Ampère Seamount, approximately 100 km west of the Strait of Gibraltar).

By using a single-frequency radar, mineral oil spills and monomolecular sea slicks cannot be distinguished by measuring the reduction of the backscattered radar power. This is because both surface films reduce the strength of the radar echo by approximately the same amount as shown by Hühnerfuss et al., (1978, 1987).

B - Multi-frequency Microwave Scatterometer

Recent radar backscattering experiments carried out by the University of Hamburg seem to indicate that it is possible to distinguish between mineral oil spills consisting of heavy fuel and natural monomolecular sea slicks by using multi-frequency radar. This is because the backscattered radar power (or the normalized radar cross section) exhibits a different behaviour as a function of radar frequency and incidence angle for these two different types of surface films. This has been demonstrated by flying over several artificial monomolecular sea slicks and marine mineral oil spills with a 5-frequency scatterometer and measuring the reduction of the backscattered power by these surface films in all five frequency bands and at different incidence angles.

The 5-frequency scatterometer, called HELISCAT, operates at 1.0 GHz (L-band), 2.4 GHz (S-band), 5.3 GHz (C-band), 10.0 GHz (X-band), and 15.0 GHz (K_u-band) and is capable of performing radar backscatter measurements at all five frequencies and at the four polarization combinations VV, VH, HH, HV. It uses a single broadband antenna for transmission and reception. The antenna is aft-looking and can be tilted mechanically such that the incidence angle on the ground varies between 23 and 65 degrees. HELISCAT was built at the Institute of Oceanography of the University of Hamburg and is designed to measure multi-frequency and multi-polarization radar signatures over water, ice and land surfaces (Wismann et al., 1993a). The system characteristics of HELISCAT are summarized in Table 2.

Several artificial sea slicks of different visco-elastic properties were deployed on the surface of the North Sea by dissiminating small chunks of frozen surface-active materials from a helicopter. After spreading, concentric slick patches evolve from chunks which merge under favourable conditions within 10 to 20 minutes to a large connected slick. The mineral oil spills consisting of heavy and light fuel were put on the North Sea during the controlled oil spill exercise SAMPLEX which took place in 1992 (Wismann et al., 1993b).

It was found that the backscattered radar power as a function of radar frequency and incidence angle exhibits the characteristic dependence as predicted by Marangoni damping theory (Lucassen, 1982, Cini et al., 1983, Ermakov et al., 1986, and Hühnerfuss, 1989).

The radar backscattering at oblique incidence angles from the sea surface can, to first order, be described by Bragg scattering theory. According to this theory the backscattered radar power is proportional to the spectral energy density of the Bragg waves; i.e., of those surface waves which have wavelengths l_B that obey the Bragg resonance condition

$$l_B = l_0 \; / \; 2 \sin u$$

Here l_B denotes the radar wavelength and u the radar incidence angle. By varying l_B and/or u the wave damping curve can be scanned as a function of wavelength or wavenumber. When using the above mentioned five radar frequency bands and incidence angles between 23 and 65 degrees, the wave damping by visco-elastic surface films can be measured in the wavelength range from 1.3 cm to 40 cm. This is the wavelength region where Marangoni resonance occurs.

The damping ratio, i.e., the ratio of the backscattered radar power from a slick-free and a slick-covered surface, depends on the elastic and viscous properties of the surface film. Thus by measuring the damping ratio as a function of Bragg wavelength l_B one can obtain informations about the rheological properties of the surface film. This offers the potential developing a radar technique capable of discriminating between surface films of different physico-chemical properties, in particular between natural surface films and mineral oil spills. The experiments carried out so far show a dependence of the backscattered radar power on Bragg wavelength l_B which is consistent with Marangoni damping theory (Alpers et al., 1991, Theis et al., 1992, Wismann et al., 1993a, 1993b).

However, additional research work has to be carried out for validating this multi-frequency radar technique for discriminating between mineral oil spills and natural surface films. We can imagine that a future oil pollution surveillance plane will include in its sensor package three microwave sensors: (1) a wide-swath imaging radar (most likely a side-looking real aperture radar), (2) a multi-frequency scatterometer, and (3) a 3-frequency microwave radiometer. The imaging radar is used for detecting the position, the areal extent, and the geometrical form of the slick, the multi-frequency scatterometer for determining the nature (visco-elastic properties) of the surface film, and the 3-frequency microwave radiometer (see below) for measuring the thickness of the mineral oil spill.

C - Microwave Radiometer

A multi-frequency microwave radiometer allows the determination of the thickness of a mineral oil spill and hence an estimation of the total amount of oil spilled. This is possible because the microwave brightness temperature is greater in the region of an oil film than in the adjacent unpolluted sea by an amount which depends upon the film thickness. The oil film acts as a matching layer between free space (low dielectric constant) and the sea (high dielectric constant) thus enhancing the brightness temperature of the sea. As the thickness of the oil film is increased, the brightness temperature at first increases and then oscillates. The strongest effects due to the oil film on the brightness temperature can be observed when its thickness is an odd multiple of a quarter of the observational wavelength in the oil. The weaker effects are obtained for a thickness which is a multiple of one half of the wavelength. The oscillating behaviour is caused by interference of radiation reflected at the upper and lower boundary of the oil layer. By using two or more frequencies, thickness ambiguities introduced by the oscillations may be removed and the film thickness determined for a wide range of thicknesses. A thickness variation of only 0.1 mm produces variations of the brightness temperature of 5-12 K, which are easily detectable by microwave radiometers.

Popular microwave bands for measuring oil layer thickness are 34 and 17 GHz. A 34 GHz channel alone gives good resolution of thin layers but their thickness can be measured unambiguously only if it is less than 1.7 mm. A 17 GHz channel alone can measure up to 3.5 mm of oil, but with poor resolution below 1 mm. A 17 and 34 GHz system combines the merits of each channel and is able to measure slick thicknesses up to 3.5 mm with good accuracy throughout the range. Addition of a 5 GHz channel to this system extends the measurement range up to 12-13 mm. Hence, the high frequency channel still measures the thickness with good resolution, while the low frequency channel solves the ambiguity problem. Radiometers in the millimeter region (e.g., 90 GHz) give precise information on thickness less than 0.4 mm and the images of the slicks resemble those obtained by infrared scanners. This helps the combating teams to recognize the shape and extension of the whole slick, while radiometers working at lower frequencies detect and locate only the spots of thicker oil.

The microwave radiometer system developed by the Technical University of Denmark at Lyngby has 3 channels operating at 5, 17 and 34 GHz (Skou, 1987), and the one developed by the German Aerospace Research Establishment DLR has 2 channels operating at 32 GHz and 90 GHz (Grüner, 1987). We recommend to use for an operational airborne microwave radiometer system 3 frequencies in the frequency range between 10 and 90 GHz, e.g., at 15, 35 and 90 GHz.

D - Multi-spectral Scanner and Imaging Spectrometer Operating in the Infrared, Visible, and Ultraviolet

Multi-spectral scanners operating in the infrared (IR), visible (VIS), and ultraviolet (UV) are useful sensors for studying the distribution of suspended matter and chlorophyll in the sea, of algal blooms, as well as the motion of mineral oil spills. Ligi et al. (1992) studied algal blooms and gel production in the Adriatic Sea, and Cecamore et al. (1992) the motion of the oil spill generated by the accident of the oil tanker "Haven" on April 11, 1991, in the Gulf of Genoa by using data from the Thematic Mapper onboard the American LANDSAT satellite and the HRV (high resolution visible) imaging instrument onboard the French SPOT satellite.

Multi-spectral scanners are also flown on aircraft, as happens with the Italian Coast Guard (Capitainerie di Porto), to provide information on the marine environment. It has been shown by Geraci and La Rosa (1992) that oil spills can be identified on thermal infrared images acquired by such airborne scanners due to the difference in the thermal emission of the clean and oil-covered water surface. An oil-covered surface has a slightly higher brightness temperature (1-2 degrees C) than the clean surface even if the thermal temperature is the same.

An airborne imaging spectrometer, called ROSIS (Reflective Optics System), having 84 available spectral channels in the spectral range from 400 nm to 850 nm with bandwidths between 5 and 10 nm, has been built by MBB (Messerschmitt-Bölkow-Blohm GmbH), Germany, in collaboration with DLR (German Aerospace Research Establishment, Institute of Commun. Techn. and Remote Sensing, Oberpfaffenhofen), and GKSS (Research Center Geesthacht). If flown on an aircraft at an altitude of 8 km, the gound pixel size is 4.4 m and the swath width +/- 2.3 km (Kunkel et al., 1987). With this instrument phytoplankton pigments, sunlight-stimulated fluorescence of chlorophyll, suspended matter, and Gelbstoffe can be sensed. A similar programmable imaging spectrometer operating in the visible spectral band (400 nm to 1000 nm), called VIRS, has been conceived by Officine Galileo, Florence, Italy (Buccheri et al., 1992).

Imaging narrow-band spectrometers are suited for measuring plankton and algae blooms, Gelbstoff concentration and suspended sediments. It has been claimed that these instruments have also the potential to detect and trace chemical waste even in the presence of sediment plumes (Kunkel et al., 1987). But this has still to be proven.

E - Fluorescence Lidar

Airborne fluorescence lidars (or laser fluorosensors) are also capable of monitoring sea pollution. A fluorosensor was first used by Kim (1973) for mapping algae. Basically the laser fluorosensor consists of a high power laser emitting at near UV or visible wavelengths, and of a gated signal receiver for the detection of laser-induced radiation from the upper water layers. Pulsed laser systems and gated signal detectors are utilized throughout in order to discriminate daylight background from the laser-induced water column return.

The airborne fluorescence lidar allows a nearly synoptic investigation of hydrographic parameters in the upper water layers over extended areas of the sea. For instance "Gelbstoffe" (dissolved organic matter, humic substances) are well detectable by this sensor. Due to its good chemical stability, Gelbstoff can be used as a natural tracer substance for the study of mesoscale transport and mixing. This concerns particularly the investigation of river water mixing in estuaries, and thus allows identification of path and dilution of dissolved pollutants present in river run-offs. In addition, the fluorescence lidar allows the detection of chlorophyll, suspended matter in the near-surface water column, and the nature of marine mineral oil slicks. Investigations have been carried out, among others, by Andersson et al. (1987) and Hengstermann and Reuter (1990, 1992) to establish the possibilities of characterizing marine mineral oil slicks by means of laser-induced fluorescence. The laser fluorescence technique exploits the fact that the fluorescence spectra of oil slicks depend on composition of the oil and of the thickness. It seems that fluorosensors can detect surface films having a thickness of the order of 10^{-6} m (Diebel et al., 1987). Research for determining oil types by this technique is still on-going.

F - Optical Sensors (Camera, Low-light TV, Human Eye)

Oil films can be detected also by the visual observations, by cameras and low-light TV cameras during daytime under favourable weather conditions. Furthermore, such sensors are indispensable for ship identification from a surveillance airplane.

It is often claimed that by visual observations from aircrafts it is possible for a trained person to estimate the thickness of an oil spill by its appearance and colour (Schriel, 1987). E.g., when the oil spill looks silver transparent, its thickness lies between 0.02-0.05 microns; when it looks blue, its thickness is approximately 1 micron; and when it looks brown, its thickness is approximately 15 microns. A thickness of 15 microns gives an oil volume per km^2 of approximately 15 m^3/km^2. We are unable to judge whether these estimates are realistic.

III. PROPOSAL FOR ACTIONS

For developing a reliable monitoring system for oil spills and organic substances in the Mediterranean we propose the following actions:

1) Analysis of ERS-1 SAR images acquired over the Mediterranean with the aim of gathering information on

(a) the frequency of discharges of oil from ships in different sea areas

(b) the areal extent of the oil spills released from ships

(c) the location of sources (sewage and industrial plants) releasing organic pollutants into the Mediterranean which float on the sea surface

2) Analysis of SeaWiFS (Sea-Viewing Wide-Field-of-View Sensor) ocean colour data from the future American SeaStar satellite (envisaged launch date: January 1994) for measuring chlorophyll and algae blooms, suspended matter and

Gelbstoffe. Furthermore, Landsat-TM and SPOT- HRV image should be included also in such an analysis.

3) Definition of an optimal sensor package for monitoring marine pollution from airplanes in the Mediterranean. Very likely this sensor package will include the following sensors:

(a) a wide-swath imaging radar (real aperture radar)
(b) a 3-frequency microwave radiometer
(c) a multi-frequency microwave scatterometer
(d) a fluorescence lidar and
(e) an imaging spectrometer of the ROSIS or VIRS type

4) Validation of the performance of the proposed sensors in controlled pollution experiments

5) Installation of these sensors on several airplanes stationed in different countries surrounding the Mediterranean

IV. REMARKS

(1) Heavy metals in the marine environment cannot be measured directly by any known remote sensing technique. However, they accumulate often in plumes of suspended matter which can be sensed by multi-spectral scanners or imaging spectrometers operating in the infrared, visible and ultraviolet.

(2) Carrying out controlled oil spill experiments for testing instrument performance in the Mediterranean may be a problem. For example, in 1981 already, the Italian authorities refused to give permission to the Joint Research Center at ISPRA to spill 300 litres of mineral oil in the Mediterranean during the ISOWAKE experiment. Later, in 1991, they refused even to give permission to the University of Florence to spread a few litres of oleyl alcohol on the sea surface during the MAC Europe'91 Campaign, when a NASA airplane carrying a 3-frequency SAR was flying over the Ligurian Sea. The spilling of oleyl alcohol was requested for studying the variation of the radar backscattering from natural and man-made monomolecular surface films as a function of radar frequency.

Systèmes opérationnels pour combattre la pollution en mer Méditerranée

par Giuseppe ANGRISANO

Bureau Hydrographique International, 7 avenue Président J.F. Kennedy, MC 98000 Monaco

1. Introduction

Cette section présente un bref survol des organisations existantes chargées de lutter contre la pollution en Méditerranée, examinant ensuite les besoins opérationnels pour faire face aux incidents majeurs liés à la pollution. Enfin le développement d'un système d'information géographique adapté est proposé comme outil de surveillance de la santé des côtes et des eaux côtières, tenant compte de l'expérience personnelle de l'auteur, acquise lors de l'accident du pétrolier HAVEN à Gênes en 1991.

2. Organisations internationales et nationales pour la lutte contre la pollution en mer

2.1 Organisations internationales

Le Plan d'Action Communautaire développé par la CCE (DG XI) a pour objectifs de soutenir les efforts des Etats membres, les aidant à améliorer leur capacité de réaction en cas d'accidents majeurs impliquant du pétrole ou d'autres substances nuisibles, et créant les conditions nécessaires à une assistance mutuelle efficace.

Qu'il s'agisse de pétrole ou d'autres substances nuisibles, les principes du Plan d'Action Communautaire sont pratiquement les mêmes, différant seulement sur les détails. Les éléments du Plan d'Action Communautaire pour le pétrole et pour les produits chimiques sont fondés sur les éléments suivants : système communautaire d'information, programmes de formation, études et projets pilotes. Dans le système communautaire d'information (SCI) sont insérées les informations concernant les organisations nationales.

Une deuxième structure internationale est constituée par le Centre Régional Méditerranéen pour l'intervention d'urgence contre la pollution marine accidentelle (REMPEC), établie en décembre 1976 à Malte. Ce centre, placée sous la responsabilité conjointe de l'Organisation Maritime Internationale (OMI) et du Plan d'Action pour la Méditerranée (UNEP/ PAM) doit s'occuper de tout type de pollution accidentelle. Le Centre a les objectifs suivants :

- renforcer les capacités des nations côtières de la Méditerranée et faciliter la coopération entre elles dans le cas de pollutions accidentelles importantes ;
- assister les Etats côtiers qui le demandent à développer les capacités de réponse aux pollutions accidentelles ;
- faciliter l'échange des données, la coopération technologique et la formation ;
- établir des normes de base pour standardiser l'échange d'informations opérationnelles, techniques, scientifiques, juridiques et financières.

2.2. Organisations nationales

Les lois nationales destinées à protéger l'environnement marin et à mettre en place l'organisation qui doit faire face aux émergences en mer tiennent généralement compte des conventions internationales et des accords bilatéraux existants.

2.2.a. l'organisation opérationnelle française

Il y a en France quatre ministères qui s'occupent de la pollution marine, à savoir : le Ministère de la Mer (jusqu'à sa disparition lors de la constitution du nouveau gouvernement le 2 avril 1993), le Ministère de la Défense (Marine Nationale), le Ministère de l'Environnement et le Ministère de l'Intérieur.

En mer la responsabilité de toutes les affaires y compris les affaires civiles en mer est du ressort des Préfets Maritimes (voir Figure 1) qui sont des amiraux dépendant du Ministère de la Défense. En particulier le Préfet Maritime de Toulon est responsable des eaux françaises méditerranéennes. Dans chaque Préfecture Maritime un bureau est spécifiquement chargé des "Actions de l'Etat en mer". En cas de nécessité le Préfet Maritime met en application le plan POLMAR MER. La figure indique clairement qu'en cas d'accident en mer il n'y a qu'une seule autorité chargée de coordonner les actions : le Préfet Maritime de la région.

2.2.b. l'organisation opérationnelle en Italie

En Italie la gestion et la lutte contre la pollution des accidents en mer est confiée à l'autorité maritime (garde-côtière) qui dépend à la fois du Ministère de la Marine marchande et de l'Etat Major de la Marine nationale. Si l'urgence prend de plus grandes proportions, il sera nécessaire de faire intervenir le Ministère de la Protection civile qui a été créé dans le but de coordonner les moyens de secours dans de telles situations. Un bureau comme PROCIVIL MARE (protection civile en mer) est principalement chargé de faire face à ce type d'accidents (voir Figure 2).

2c. Organisation dans les autres nations

Ces deux exemples d'organisations nationales pour faire face à la pollution démontrent deux différents moyens d'approche du problème. Les pays côtiers de la Méditerranée ont ou auront une organisation similaire à celle de la France ou de l'Italie. La liste complète des Centres et Ministères chargés de la lutte contre la pollution marine est donnée dans la publication *Régional Information System* éditée et tenue à jour par le Centre Régional Méditerranéen pour l'Intervention d'Urgence contre la Pollution Marine Accidentelle établi à Manoel Island, Malte, depuis le 11 décembre 1976.

Cette publication fait apparaître que généralement la gestion des urgences causées par des pollutions marines est centralisée et que c'est l'Etat qui s'en occupe. Chaque pays possède ou envisage de mettre en place un ou plusieurs centres de surveillance (dans le cas italien, il y a la Protection civile, branche marine, et le Centre pour la Défense de la Mer auprès du Ministère de la Marine marchande). Dans le cas français CROSSMED LAGARDE est chargé de recevoir les messages d'alerte.

Système opérationnel de lutte contre la pollution marine en France

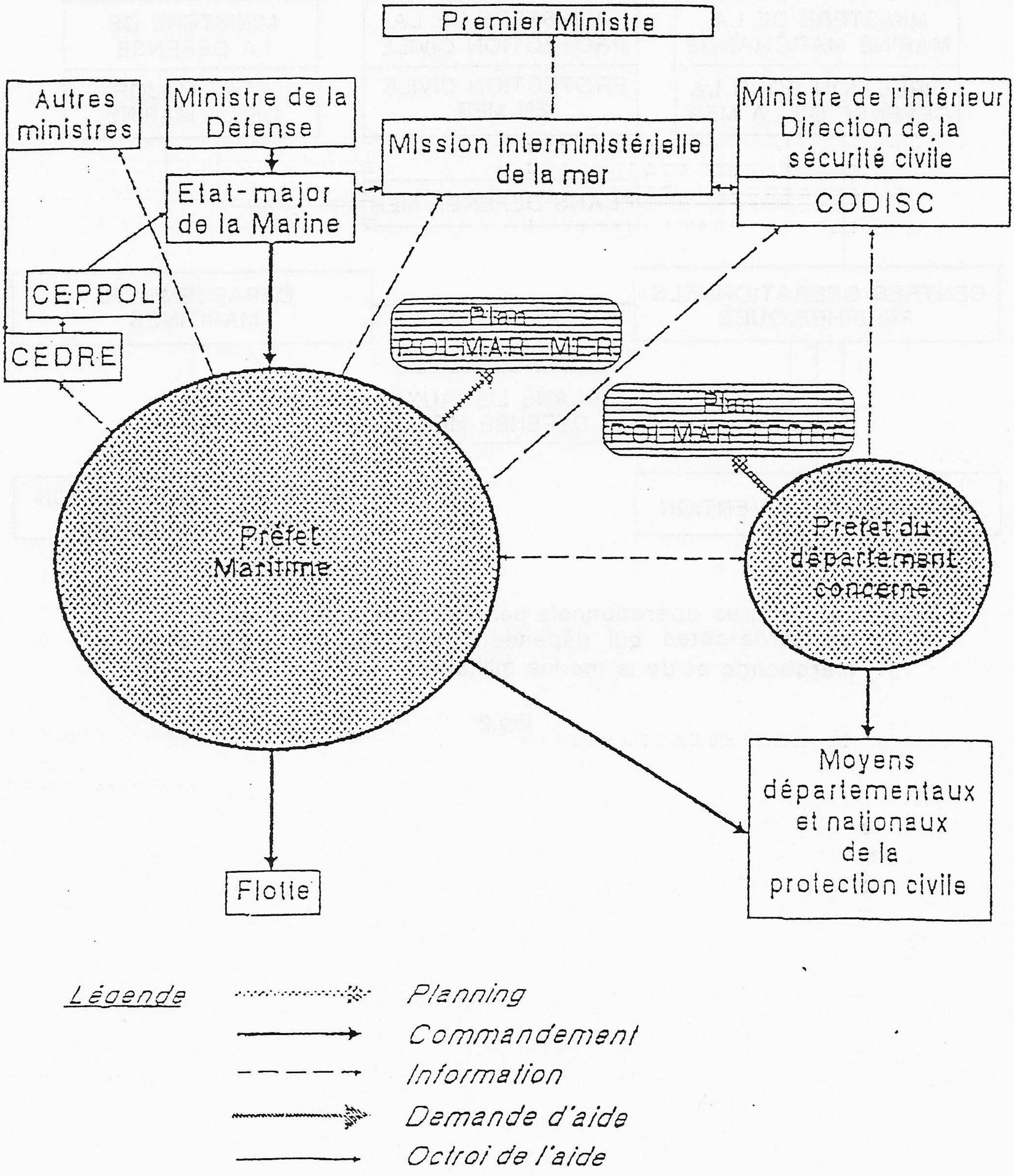
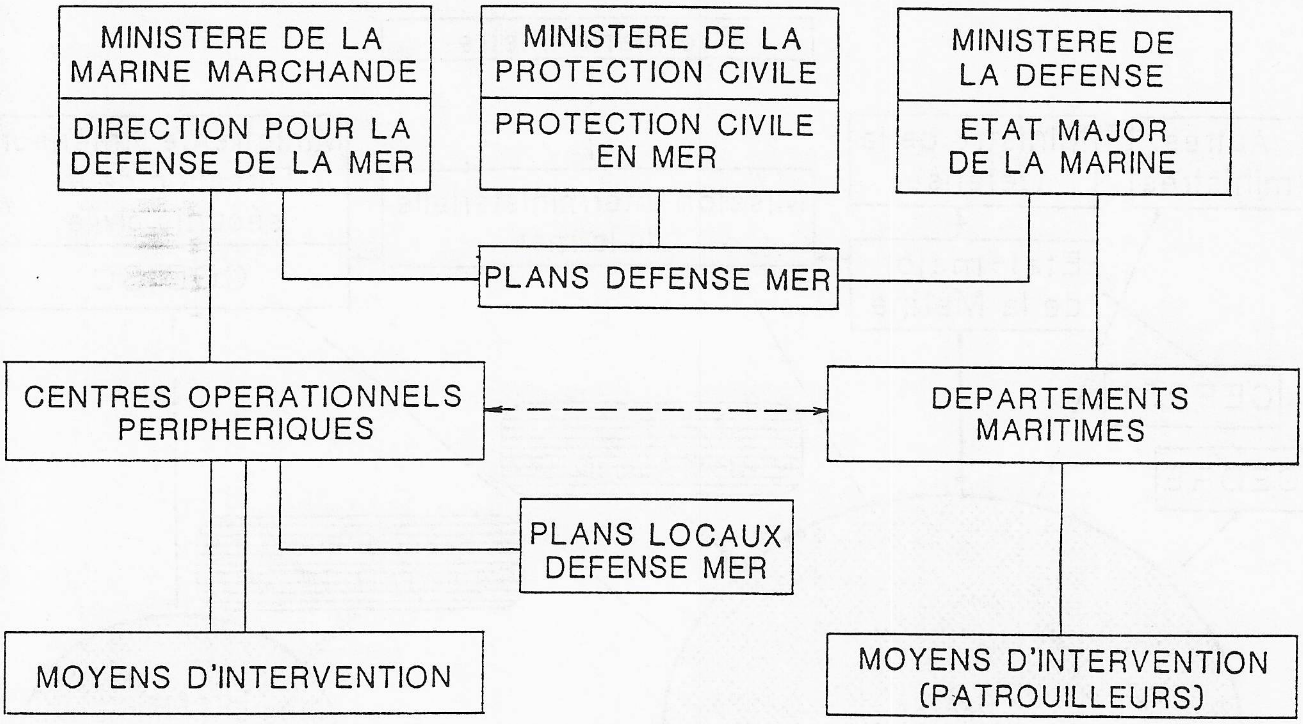


Fig.1

SYSTEME OPERATIONNEL DE LUTTE
CONTRE LA POLLUTION MARINE EN ITALIE



Note : Les centres opérationnels périphériques sont gérés par les Garde-côtes qui dépendent à la fois de la marine marchande et de la marine militaire

Fig.2

3. Lutte contre la pollution : problème opérationnel

La protection de la mer a pris donc depuis quelques années l'aspect d'un problème opérationnel, face auquel des plans et moyens adéquats gérés par un système bien clair de "commande, contrôle et communications"sont nécessaires. Ceci fut particulièrement évident lors du développement de l'accident du pétrolier HAVEN, survenu à Gênes (Italie) en avril 1991.

Dans ce cas précis les opérations de secours et de dépollution furent conduites par le Centre Opérationnel Périphérique de Gênes de la garde côtière italienne, selon ce qui est prévu par la législation italienne. Il s'agissait d'une zone côtière de trente à quarante milles polluée par un pétrolier (le HAVEN), qui au moment de l'accident (explosion à bord, le bateau était mouillé dans la rade de Gênes) transportait 140 000 tonnes de pétrole iranien et a brûlé pendant deux jours et demi. Les opérations de secours, de remorquage du navire, de protection initiale des côtes et de dépollution ont requis l'emploi de nombreux moyens navals (plus de 20) et aériens, ainsi que des opérations immédiates de dépollution le long des côtes et d'inspection de l'épave du bateau coulé à 1,5 mille de la côte.

Toutes ces opérations se sont déroulées régulièrement et le résultat a été satisfaisant grâce à l'oeuvre infatigable des hommes de la garde côtière italienne. Toutefois le Commandant du Centre Opérationnel Périphérique de la Ligurie et les autres décideurs au niveau central et local auraient pu être mieux aidés s'ils avaient disposé d'un Système d'Information Géographique (SIG) capable de donner sur écran les informations géographiques de base, liées à des informations sur l'accident, les moyens de secours et la dépollution. Les paragraphes suivants donnent une description du système d'information géographique envisagé.

4. Les informations de base requises

Afin de donner aux planificateurs toutes les informations dont ils ont besoin pour rédiger les plans d'intervention contre la pollution marine, il faut créer une base de données organisée sous forme d'un système d'informations géographiques (GIS) et gérée par les institutions publiques afin qu'elles puissent comprendre et restituer sous forme claire tous les renseignements pertinents concernant, et notamment sur les paramètres suivants:

- topographie côtière
  - ligne de côte et nature de la côte
  - réseau routier
  - installations touristiques (ports de plaisance inclus)
  - installations industrielles
  - zones protégées sur la côte
  - installations portuaires
  - installations d'importance vitale (par ex. centrales électriques)
  - plages
  - embouchures des fleuves et des torrents
- Informations hydrographiques :

- bathymétrie
- sédimentologie et géologie du fond
- nature du fond en général
- zones archéologiques sous-marines
- épaves
- zones d'exploitation des fonds marins

- Informations océanographiques :
  - hydrologie (température, salinité, oxygène, etc.)
  - courants
  - marées
  - biologie marine (prairie de posidonie, ressources en poissons, aquaculture etc..)

- Informations concernant la pollution chimique :
  - emplacements des conduites sous-marines (égouts)
  - embouchures des fleuves et des torrents
  - emplacements des puits sous-marins en production
  - résultats des études de diffusion des polluants selon leur composition et selon les conditions météorologiques : ces résultats devraient indiquer les zones où il y a excès de nutrients et/ou de polluants chimiques toxiques.

5. Création d'un Système d'Information Géographique pour la gestion côtière

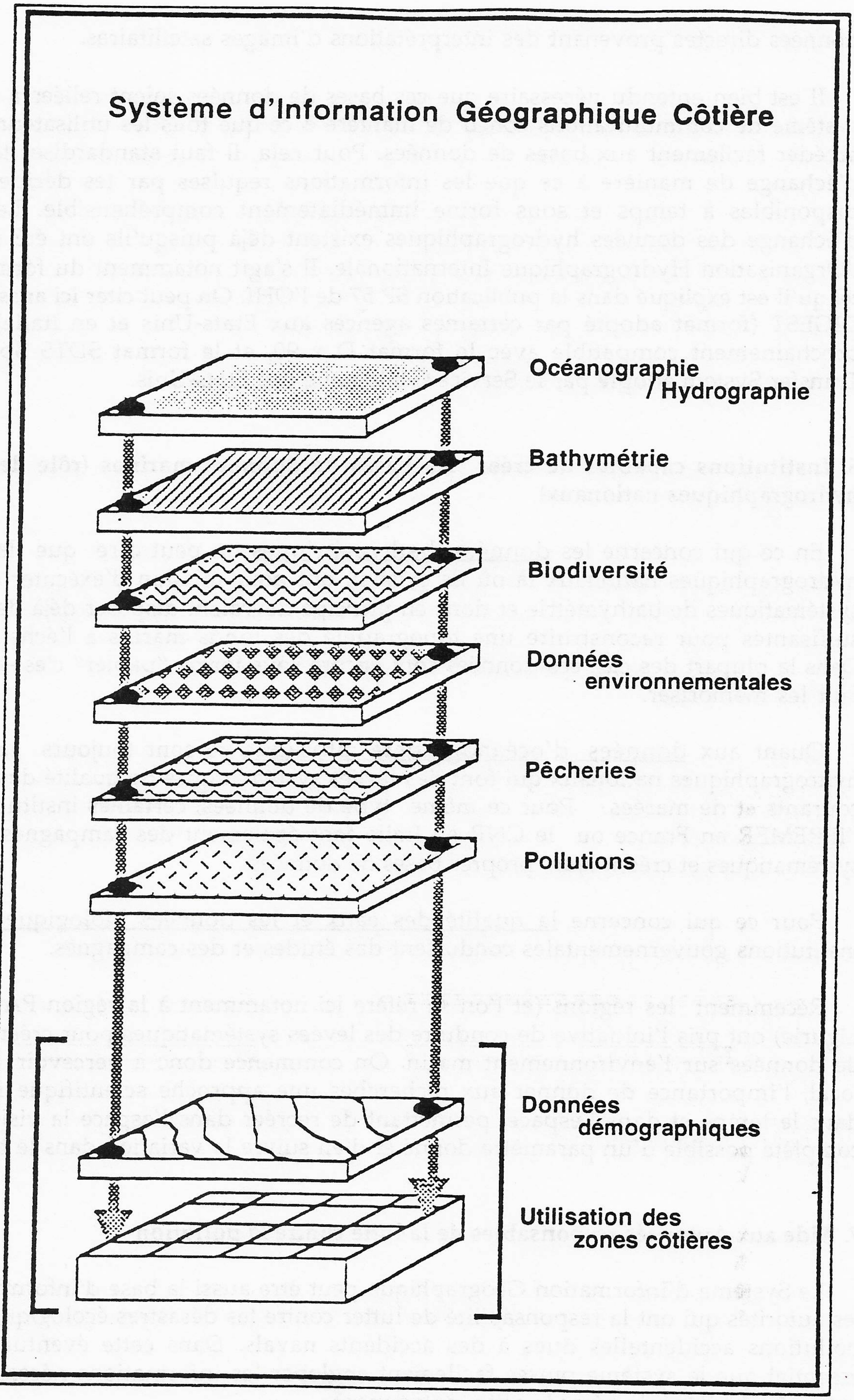
La création d'un système électronique géographique d'informations s'impose qui puisse complètement intégrer les informations de base gérées par les institutions gouvernementales, par les institutions académiques et les administrations locales (régions, provinces, villes) concernées.

Aujourd'hui il existe plusieurs systèmes d'informations géographiques qui peuvent intégrer, gérer et présenter des grandes masses d'informations géo-référenciées mises à disposition, à travers un réseau informatique, par les institutions responsables des bases de données dans les différents domaines de la recherche.

Le SIG (GIS) permet la corrélation des données appartenant à différents groupes sur la base de leur appartenance à un système commun de coordonnées géographiques. La structure commune est donc le système de repérage géographique (voir Figure 3). S'agissant de la mer, les données bathymétriques et géodésiques deviennent fondamentales pour les informations sur le territoire.

Chaque couche dans le SIG donne des informations sur différents paramètres comme l'océanographie physique, biologique et chimique, les données fluviales, l'évaluation de l'environnement côtier, la gestion de la pêche, l'usage des côtes, etc...). Dans le cas de la Méditerranée il s'agirait de pouvoir créer un système d'information géographique qui intégrerait des bases de données existantes.

La figure 4 présente un schéma d'intégrations possibles des bases de données qui existent et qui pourraient exister dans la zone méditerranéenne. Au centre du schéma apparaît une observation hypothétique de la Méditerranée qui serait basée sur des


Système d'Information Géographique Côtière
Océanographie / Hydrographie
Bathymétrie
Biodiversité
Données environnementales
Pêcheries
Pollutions
Données démographiques
Utilisation des zones côtières

données directes provenant des interprétations d'images satellitaires.

Il est bien entendu nécessaire que ces bases de données soient reliées à travers un système de communications conçu de manière à ce que tous les utilisateurs puissent accéder facilement aux bases de données. Pour cela, il faut standardiser les formats d'échange de manière à ce que les informations requises par les décideurs soient disponibles à temps et sous forme immédiatement compréhensible. Les formats d'échange des données hydrographiques existent déjà puisqu'ils ont été établis par l'Organisation Hydrographique Internationale. Il s'agit notamment du format D x 90 tel qu'il est expliqué dans la publication SP 57 de l'OHI. On peut citer ici aussi le format DIGEST (format adopté par certaines agences aux Etats-Unis et en Italie), qui sera prochainement compatible avec le format D x 90, et le format SDTS Special Data Transfer System adopté par le Service Géologique des Etats-Unis.

6. Institutions capables de créer les bases de données marines (rôle des services hydrographiques nationaux)

En ce qui concerne les données bathymétriques on peut dire que les services hydrographiques nationaux là où ils existent ont pour mission d'exécuter des levées systématiques de bathymétrie et donc en principe devraient disposer déjà des données suffisantes pour reconstruire une topographie des fonds marins à l'échelle voulue. Dans la plupart des cas, ces données sont encore sous forme "papier" c'est-à-dire qu'il faut les mémoriser.

Quant aux données d'océanographie physique ce sont toujours les services hydrographiques nationaux qui font des levées systématiques de qualité des fonds, de courants et de marées. Pour ce même type de données, certaines institutions telles l'IFREMER en France ou le CNR en Italie font également des campagnes de levées systématiques et créent leurs propres bases de données.

Pour ce qui concerne la qualité des eaux et les données biologiques d'autres institutions gouvernementales conduisent des études et des campagnes.

Récemment les régions (et l'on se réfère ici notamment à la région PACA et à la Ligurie) ont pris l'initiative de conduire des levées systématiques pour créer des bases de données sur l'environnement marin. On commence donc à percevoir, au niveau local, l'importance de donner aux recherches une approche scientifique rigoureuse dans le temps et dans l'espace, permettant de recréer dans l'espace la vision la plus complète possible d'un paramètre donné et d'en suivre la variation dans le temps.

7. Aide aux Autorités responsables de la lutte contre la pollution

Le Système d'Information Géographique peut être aussi la base d'information pour les autorités qui ont la responsabilité de lutter contre les désastres écologiques tels que pollutions accidentelles dues à des accidents navals. Dans cette éventualité, il est essentiel que le système puisse facilement englober les informations nécessaires aux autorités chargées de gérer la crise, notamment :

- situation météorologique (analyse de surface, prévision à moyenne échelle)

- situation océanographique (courants, vagues)
- situation de surface (identification et traçage des navires présents dans la zone)
- localisation et traçage des navires impliqués dans l'accident
- localisation et traçage des polluants présents dans la zone
- localisation et traçage des moyens de secours et dépollution
- situation aérienne (localisation et traçage des patrouilleurs maritimes et des hélicoptères)

Ce type d'information devra être représenté et mis à jour en temps réel et avec la plus grande clarté. L'Organisation Hydrographique Internationale (OHI) a mis au point les spécifications pour la carte de navigation électronique et pour sa mise à jour. Ces spécifications ont été soumises à l'approbation de l'Organisation Maritime Internationale (OMI) et l'on peut prévoir qu'à partir de 1995 cet instrument commencera officiellement à remplacer la "carte papier".

Il s'agira d'un instrument très sophistiqué doté d'une représentation couleur et d'une symbologie très précise. Le format de saisie des données en a déjà été établi, ainsi que les modalités pour la mise à jour automatique, pour la représentation d'informations non cartographiques, et pour la mémorisation d'événements. Dans ce contexte, l'adaptation de la base de données de la carte électronique de navigation aux besoins de la gestion d'une crise de pollution pourrait s'avérer très utile.

8. Nécessité d'un projet pilote

Pour réaliser le Système d'Informations Géographiques capable de gérer aussi des situations de crise il semble nécessaire de développer un projet pilote d'approche globale. Il s'agira d'étudier dans un premier temps le développement d'un système intégré et opérationnel de surveillance et de contrôle de la qualité d'un milieu marin.

Un tel système devra répondre aux besoins en matière de mesures, de modèles et de technologies à mettre en oeuvre pour la protection de l'environnement marin avec pour objectifs généraux la protection de la santé humaine, l'évaluation de l'efficacité des mesures prises, l'étude de l'état des ressources exploitées, la connaissance de la vie marine et des niveaux de pollution existants et de leur évolution.

Un tel système devrait disposer :
a) d'une forte intégration fonctionnelle et matérielle
b) d'une large multidisciplinarité
c) d'une collaboration internationale

a. <u>intégration</u>

Si les expériences passées et en cours, de réseaux spécifiques de surveillance de l'environnement ont permis d'en démontrer la faisabilité technique, elles ont cependant aussi montré leurs limites d'utilisation. Une spécialisation excessive ne permet en effet pas à de tels réseaux une généralisation de leurs principes ni une extension de leurs objectifs. En outre, ils ne permettent pas, en eux-mêmes, de constituer des aides efficaces à la décision faute de fournir l'ensemble des informations à prendre en compte, dans une synthèse globale.

Le programme souhaité devrait se placer donc d'emblée sur un objectif plus global de surveillance d'une zone sensible et à risques, permettant de répondre à plusieurs besoins complémentaires (santé, environnement, ressources...). Une intégration fonctionnelle (données, résultats, ...) et matérielle (capteurs, bases de données) offrira de plus globalement une économie substantielle des moyens nécessaires à l'ensemble de ces besoins complémentaires.

b. multidisciplinarité

La réalisation d'un tel programme nécessitera des compétences et expertises nombreuses et variées, à la fois :
- scientifiques : biologie; chimie, modélisation ....
- techniques : capteurs, réseaux, informatique, intelligence artificielle ...
- industrielles méthodologies, projet, planification ...
- opérationnelles : interventions à la mer, interfaces utilisateurs, maintenance.

Les besoins futurs des utilisateurs et des décideurs concernés devront être pris en compte, ainsi que la législation internationale, le droit de la mer et l'ensemble des moyens d'intervention. L'organisation serait ainsi basée sur des groupes de travail interdisciplinaires qui devraient être coordonnés par un comité technique couvrant l'ensemble des compétences requises.

c. collaboration internationale

La circulation et l'impact des apports polluants ne connaissent pas de frontières. Une collaboration internationale est donc préalable à tout programme de cette envergure.

Zone pilote

On pourrait envisager de désigner le bassin corso-liguro-provençal et ses eaux côtières comme zone pilote de ce projet. Alternativement le projet pilote pourrait s'appuyer sur la coopération de deux ou trois larges villes côtières (par exemples Barcelone, Marseille, Gênes) qui développeraient en commun, et en partenariat avec des industries de haute capacité, un système adapté de surveillance intégré.

Système de surveillance intégrée

La protection du milieu marin côtier nécessite une surveillance appropriée en continu permettant d'apprécier les niveaux et tendances à moyen et long termes des paramètres généraux de qualité des eaux, et de détecter toute variation du milieu pouvant entraîner des conséquences néfastes pour l'écosystème (ensemble d'éléments biologiques et physico-chimiques en situation d'équilibre).

Un bilan synthétique pour l'aspect complet des capteurs, éprouvés ou en cours de développement, sera donc effectué de manière à évaluer les différentes configurations de systèmes possibles :

- Capteurs visuels et infrarouges
- Analyseurs physico-chimiques
- Sonars, Radars, Lidars
- Analyseurs biologiques

De même, le choix des plates-formes (support des capteurs) et la stratégie d'acquisition des données seront optimisés en fonction des contraintes économiques :

- Stations de fond et de surface
- Satellites
- Avions, hélicoptères
- Navires, véhicules autonomes

La prise en compte potentielle d'une telle diversité de sources d'information nécessite une architecture fonctionnelle et matérielle à la fois flexible et ouverte, permettant d'intégrer les moyens existants et nouveaux pour une synthèse globale des pollutions marines chroniques et accidentelles.

Plusieurs stations périphériques locales dédiées à certains capteurs ou sous-réseaux effectueront la réception des données brutes, un pré-traitement et un contrôle local. Les données pré-traitées et celles provenant de banques de données nationales et internationales seront alors envoyées à un Centre de Supervision et Contrôle (CSC) qui, d'une part, les archivera et, d'autre part, les intégrera entre elles pour fournir - en temps réel- des images synthétiques de la situation globale, portant par exemple sur :

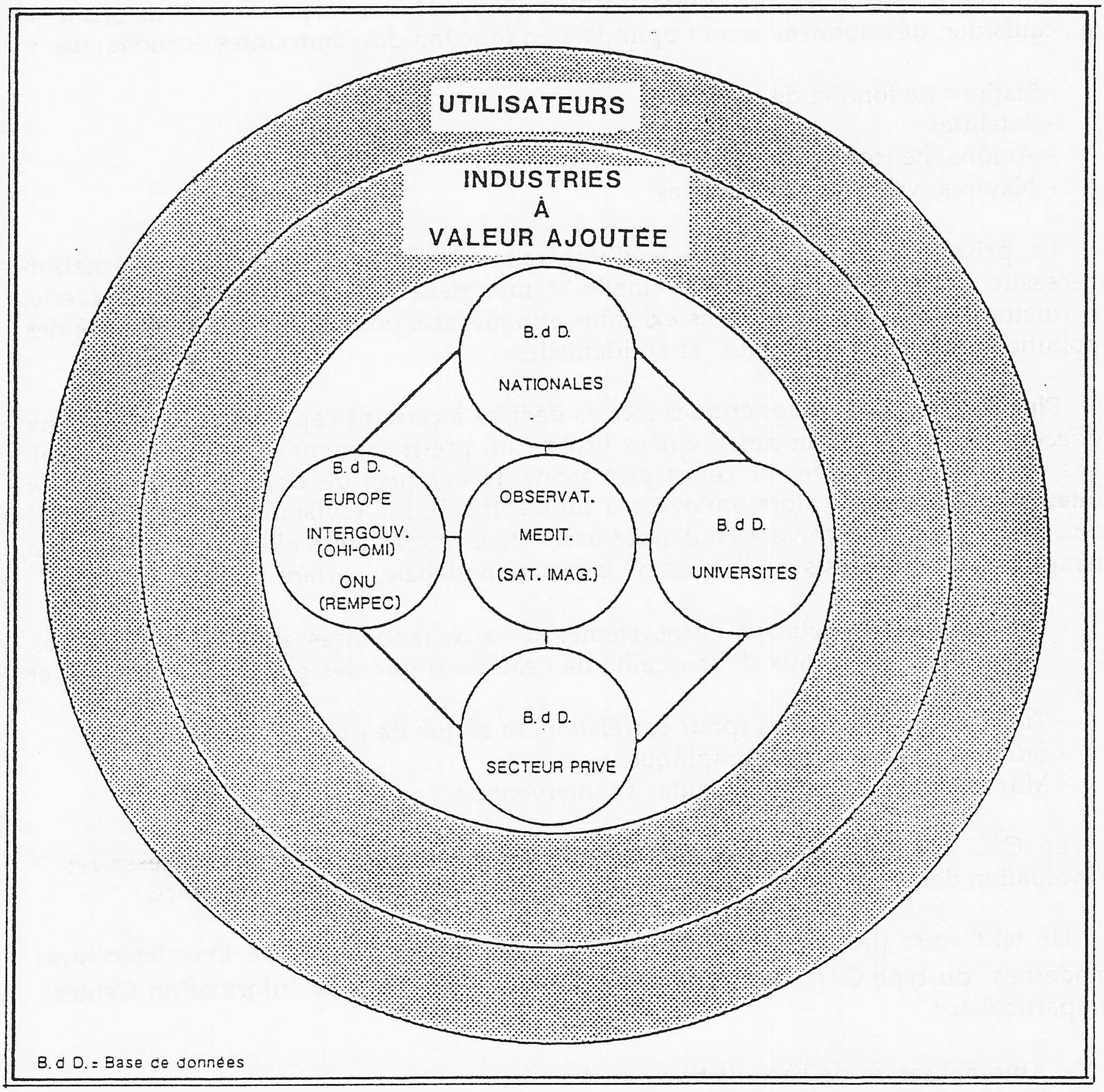
- Pollution et impacts sur l'écosystème; niveaux, tendances et seuils d'alerte des paramètres généraux de la qualité de l'eau ainsi que des polluants chimiques et biologiques
- Trajectoires des navires (pour corrélation au risque de pollution accidentelle)
- Situation météo-océanographique
- Moyens disponibles pour l'aide à l'intervention.

Le CSC doit être, de plus, équipé de l'ensemble des moyens nécessaires à l'évaluation des risques et à l'aide à la décision pour les opérations d'urgence.

Un tel Centre présente ainsi plusieurs caractéristiques communes avec les centres modernes du type C^3I (Command control, Communication & Information Center), en particulier :

- Automatisation de l'acquisition des données
- Automatisation du traitement de veille
- Association et fusion de données diverses (banques de données nationales et internationales)
- Gestion et archivage à long terme (Base de données)
- Visualisation et représentation des informations sous des formes adaptées à la prise de décision 'Systèmes d'Information Géographique de type marin)
- Aides à la décision et systèmes experts
- Réseaux de transmission et de communication fiables

Le développement de systèmes complets de ce type nécessite une méthodologie



LE CONCEPT DES BASES DE DONNEES INTEGREES

Fig.4

déjà éprouvée dans d'autres secteurs. A ce titre, la présence d'industriels reconnus dans ces domaines est une garantie pour la qualité des solutions qui seront proposées.

Le CSC devra d'autre part être interconnecté aux centres régionaux d'intervention, de façon à leur fournir toute information utile à leurs missions. La structure modulaire du système permettra une duplication de ses éléments principaux, et par exemple l'implantation d' une Centre de Supervision et de Contrôle pour chaque nation participant au programme.

Cette possibilité sera analysée dans une optique de collaboration internationale, afin d'harmoniser au mieux les différentes procédures nationales existantes.
De même, les implications légales d'une procédure de contrôle transnationale seront prises en compte.

9. Conclusions et recommandations

Il faut bien constater le caractère encore épisodique de la lutte contre la pollution en mer Méditerranée, les organisations existantes étant surtout liées aux accidents qui sont arrivés ou qui peuvent arriver. Dans les Etats plus développés technologiquement, les organisations devant faire face aux accidents de pollution sont généralement efficaces et bien équipées. Il n'en est pas de même des organisations qui doivent mettre en place des systèmes de veille, d'information géographique et d'aide aux décisions.

Il faut donc que les institutions européennes donnent des directives précises concernant la mise en place d'un système d'information géographique, la standardisation des méthodologies en vue de déterminer le degré de pollution ainsi que les formats d'échange des paramètres. Sur ce plan, les résultats acquis par l'OHI en matière d'échange de données pour la cartographie marine pourraient être considérés comme le point de départ vers une plus ample standardisation des données autres qu'une information géographique de base.

Un projet pilote de grande ampleur, tel que celui mentionné au paragraphe 8, et basé sur un partenariat actif avec la composante industrielle, apparaît donc éminemment souhaitable.

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9. Conclusions et recommandations

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Un projet pilote de grande ampleur, tel que celui mentionné au paragraphe 8, et basé sur un partenariat actif avec la composante industrielle, apparaît donc entièrement souhaitable.

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