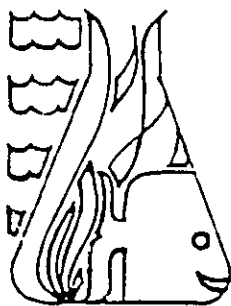


**EUTROPHICATION AND MUCOUS AGGREGATES IN  
THE NORTH ADRIATIC SEA**



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## EUTROPHICATION AND MUCOUS AGGREGATES IN THE NORTH ADRIATIC SEA

### Phytoplankton blooms

One characteristic of eutrophic coastal waters is a high frequency of algal blooms, including toxic and non-toxic taxa. It also appears that increasing anthropogenic loads are possibly responsible for increasing bloom frequencies throughout the world's coastal oceans (Anderson, 1989; Smayda, 1990). The North Adriatic Sea is typified by these recurring blooms of "nuisance algae" leading to accumulation of toxins in local shellfish and regional oxygen deficits. The principal control of blooms is river discharge with flow providing vertical and horizontal stratification and nutrients required for growth. Phytoplankton growth in response to these loads will likely be maintained and, dependent on local and/or regional heterogeneity in circulation and stratification, blooms will continue to impact the aquatic food webs.

### Biological and physic characteristics

#### *Characteristic Blooms of the Northern Adriatic*

In the Northern Adriatic Sea conditions favoring bloom development are most often observed in the coastal areas of Emilia Romagna. Here nutrient loads are higher than in all other parts of the basin due to freshwater inputs of the Po River and of minor rivers along the coast. Peak flows in spring and autumn, and less frequent summer pulses, lead to enhanced phytoplankton production and in particular dinoflagellate blooms in the region since 1975 (Mancini et al., 1980). The typical seasonal distribution in the region processed as follows: Low water temperatures prevented bloom expression in the winter. After early spring diatom increases, dinoflagellate blooms generally commenced in March-April. The principals contributors were *Noctiluca miliaris* and *Glenodinium lenticula*, followed by early summer blooms of *Prorocentrum micans*, *P. scutellum*, *Scrippsiella trocoidea* and *G. foliaceum*. In summer-fall, *Gymnodinium corii* (Viviani, 1983), *Gonyaulax polyedra* (Montanari and Rinaldi, 1983) and *Katodinium rotundatum* prevailed (Boni, 1983; Boni et al., 1983; Vollenweider et al., 1992). In most cases, the blooms were heterogeneously distributed along the Emilia Romagna coast, decreasing in intensity from north to south, likely partially explaining distributions of chlorophyll observed in the region (Vollenweider et al., 1992). The patchy distribution of the blooms also reflected variability in small tributary discharge in the area, with blooms localized to mouths of the small rivers.

#### *Blooms in Other Parts of the Northern Adriatic Basin*

Other regions of the basin and coastal bays are typified by bloom more frequently observed in the early summer. For example, in June, 1977, a bloom of *Noctiluca miliaris* was noted in the Gulf of Trieste (Cassinari et al., 1979), persisting one week and

concentrated in the inner and more confined part of the harbor. The bloom was triggered by a sudden increase in surface temperature (15-16°C to 19-20°C in a few days) associated with an increase in tributary runoff of nutrient-rich freshwater (Fonda-Umani, 1985). In the same summer, some of the same taxa noted above in the seasonal distribution of bloom forming taxa, *Gymnodinium corii* and *Gonyaulax polyedra*, were observed along the Emilia Romagna coast (Boni, 1983), lasting from July 19th to the 27th, followed in August by a *Prorocentrum micans* red tide. In June, 1980, another bloom of *N. miliaris* occurred but was far more widespread, affecting the whole northern portion of the Adriatic, from the coast of Istria to Venice (Bianchi et al., 1982; Malej, 1983; Fonda-Umani et al., 1983). This taxon was not observed along the Emilia Romagna coast where another *P. micans* bloom was noted (Boni, 1983). At the end of summer, frequently only one bloom-forming species has impacted the entire whole northern basin, with *Gonyaulax polyedra* in September, 1978 and again from August-September, 1982; however, late summer densities were generally lower than densities reported for early summer blooms of the same taxon.

Occasionally, blooms have been noted late in the year. In fall, 1984, a bloom of *Gymnodinium* was observed throughout the northern Adriatic Sea, persisting from September until December (Artegiani et al., 1985). The bloom developed along the Emilia Romagna coast after a collapse of the dense blooms of diatoms and later, *G. polyedra*, and extended 20 km offshore. New nutrient influx was responsible for the bloom: heavy precipitation lead to high freshwater inputs and associated new nutrient loads from the scouring of river bed nutrient stocks that had accumulated in a meteorologically calm period prior to mid-August (Vollenweider et al., 1992).

## Triggering factors

### *Initiation of Northern Adriatic Blooms*

Annual blooms of individual bloom-forming species are not typical of most of the Northern Adriatic Sea. Only isolated bays on the coast and the shallow region immediately south of the Po River delta have conditions favoring frequent bloom activity, with the latter area bloom-dominated because of (1) a near continuous supply of new nutrient from the Po and small rivers, (2) tidal- or meteorologically-induced mixing of remineralized nutrients, vegetative cells and resting stages from the shallow bottom, (3) persistent, stable fronts (convergences) between the nutrient-rich plume and oligotrophic offshore water and (4) wind-induced upwelling of deep, nutrient-rich bottom water from intermediate or deep basin water immediately to the east. In the summer, river discharge is minimal so that nutrients delivered in the eastward-spreading summer plume are quickly diluted, restricting bloom development to the western-most portions of the basin. Blooms occurring further east quickly assimilate fluvial inputs yielding low nutrient concentrations in surface waters. Nutrient uptake at depth via vertical migration provides little substrate for maintaining bloom populations to nutrient-depleted intermediate water; deeper migrations would require dinoflagellates to swim through the well-developed pycnocline, a behavior generally avoided by many migratory dinoflagellate populations (e.g. Cullen et al., 1985). Further, remineralized nutrient pools as well as "seed populations" in deep bottom water are rarely introduced into surface water due to strong vertical stratification and depth, thereby restricting surface

production to new nutrient in the plume and surface regeneration in increasingly oligotrophic water. Thus, blooms in the basin would reflect new nutrient inputs and be short-lived due to rapid exhaustion of nutrient pools.

#### *Western-shore enhancement of blooms*

Blooms in the Northern Adriatic Sea appear to be in response to "new" nutrient loads entering the basin. Freshwater input with its associated nutrient load stimulates bloom development in the immediate vicinity of the Po delta (reflecting storm-induced runoff in the Po River valley) as well as in the vicinity of the small minor rivers along the western side of the basin (Cacciamani et al., 1992). The increase in nutrient coupled with calm, stratified conditions support dinoflagellate blooms, conditions achieved after a period of sunny weather typical of anticyclonic conditions including a weak pressure gradient and low wind strength (Cacciamani et al., 1992). Three bloom periods are readily differentiated in the region: 1) following the late spring-early summer diatom bloom period directly controlled by Po River inputs, surface nutrients are exhausted and surface heating has stabilized the upper water column. Dinoflagellate blooms start developing using motility and migration behavior to assimilate nutrient stored at or below the deeper pycnocline; 2) during summer, surface waters remain nutrient depleted and dinoflagellates rapidly respond to local nutrient loads yielding small localized blooms usually associated with river mouths. Local sewage discharge along the whole coast can also act in a similar manner to the small river discharges contributing to available nutrient pools and localized blooms. Wind-induced upwelling of nutrients into the euphotic zone can also form the same function (Galliani et al., 1992); 3) rainfall-induced freshets in autumn lead to brief diatom blooms followed, as in spring, by blooms of dinoflagellates. Durations of spring and summer blooms appear to be limited by nutrient availability while autumn events are more strictly related to stable meteorological conditions and it could be more probably photolimitation.

The October, 1984, *Gymnodinium* bloom exemplifies this latter process. Intense precipitation in mid-August brought new nutrients previously accumulated in river beds into the coastal basin leading to an initial diatom bloom subsequently replaced by a bloom of *G. polyedra*. In September, *Gonyaulax* was in turn replaced by *Massartia* (*Katodinium*) in the north and *Gymnodinium* in the south (Vollenweider et al., 1992). With winds blowing seaward (libeccio), the bloom spread over a large area, later invading the whole northern basin (Artegiani et al., 1985).

#### **Environmental consequences**

Large excursions in oxygen concentrations are typical for the areas affected by algal blooms. Surface layers are often oversaturated, but occasionally can be undersaturated, although oversaturation in bottom waters also may occur. Prolonged periods of hypoxia and anoxia over large areas of Emilia-Romagna coasts, mostly parallel with the shore and up to some 5 km offshore, can be catastrophic for the ecosystem causing severe fish and benthic fauna kills. The effects of the blooms on oxygen and accordingly, the effects on the whole metabolic dynamics of this area, have been sometimes dramatic. As an example, during 1984, at the peak of algal blooms, oxygen concentrations in surface

waters reached values up to 170%; such peaks were followed on at least three occasions by drops to practically zero oxygen inshore. This was due to the mixing of surface waters with anoxic bottom waters sucked inshore by offshore winds. Events of this nature caused wide-spread fish kills, the stranding of dead fish along the shore in early September, and decaying biomass producing obnoxious stench of hydrogen sulphide which could be noted several km inland. The development of anoxia bottom water zones had their own dynamics. Starting south of the Po delta in mid August, the anoxic zone extended progressively south parallel to the coast reaching Rimini in the first week of September. This rapid expansion was not only produced *in loco* but was probably helped by bottom currents to the south. While surface waters were often oversaturated during the rest of the year due to continuing algal blooms, the oxygen conditions in bottom waters remained much better in later months, due to lower water temperature and reduced bacterial activity (Vollenweider et al., 1992).

### **Mucous Aggregates (“Mare Sporco” phenomenon)**

#### *Temporal and Spatial Considerations*

Red tides were common to the Northern Adriatic until 1987. Thereafter, another nuisance phenomenon appeared, macroscopic mucus aggregations. These accumulations of mucilage, visible also with remote sensing techniques, affected the entire northern basin in the summers of 1988, 1989 and 1991, apparently displacing dinoflagellates as blooms along the Emilia Romagna coast were absent in the mucilage-rich years. In 1990, no mucilage accumulation was observed and dinoflagellates were recorded, from March-April to August.

Macroscopic mucus aggregations in the Adriatic display a variety of different appearances. The accumulation, the “mare sporco” phenomenon, is described by Stachowitsch et al. (1990) as a “creamy surface layer” and a “gelatinous surface layer”. However, the phenomenon is not new, first reported as the “mare sporco” (dirty sea) in the northern Adriatic in 1729 (Della Torre Tassis, 1748), followed by other outbreaks in 1872 (de Syrski, 1872), 1880 (De Toni, 1891), 1903, 1905 (Forti, 1906), 1920, 1930 (Fonda-Umani et al., 1989) and possibly 1951 (Canadija, 1951). In 1976 and 1983, mucilage accumulation was isolated in the Kvarner region (Pucher-Petkovic and Marasovic, 1987). In the summer of 1988, 1989 and 1991, large aggregation of gelatinous masses were noted throughout the Northern Adriatic, spreading along the eastern and western coasts; in 1990, it occurred only in the Kvarner area. Few reports are available for the 1988 phenomenon because of the general lack of the regional experience and universal surprise: few recognized the nature of the phenomenon and its similarity with previous observations of the past century. It appears that aggregates were first visible in mid-July, earlier in the eastern basin areas than in the other regions. In 1989, gelatinous layers were formed in areas between low and high salinity waters and appeared earlier in the eastern transitional areas than in western regions. In 1991, larger aggregates were first noticed in the water column of the north-eastern Adriatic, including the Kvarner area, in the last week of June. Approximately two weeks later, suspended gelatinous aggregates and surface layers were present throughout most of the Northern Adriatic, except the Kvarner areas. Generally, the gelatinous material became most concentrated along frontal systems with time, particularly well-developed in the western

region off the Po delta (Degobbi et al., 1995). During the remainder of summer, distributions were dependent on both advective transport by the eddy circulation pattern, characteristic of the season (Franco, 1973; Franco and Michelato, 1992) and local winds (Degobbi et al., 1995).

### Biological and physic characteristics

Taxonomic composition of the algal assemblage must be an important factor in mucilage production since previous work indicates that exudate production is species-specific, both quantitatively and qualitatively, with the sticky properties of the released products linked to the producer species. Degobbi et al. (1995) suggest that mucus aggregates should be produced by a few species of diatoms (e.g., *Cylindrotheca closterium*, *Skeletonema costatum* and *Chaetoceros* spp.) that grow within the aggregated mucus material (Monti et al., 1995a). These species, found in late spring communities at modest levels, are the most abundant aggregate taxa and persist in macro-aggregates in summer (Revelante and Gilmartin, 1991). This accumulation occurs later in the stratified (e.g., pycnocline) layers and larger aggregates may be formed directly by coagulation of gel-dispersed material, entrapping plankton cells (perhaps including *Cylindrotheca*, *Skeletonema* and *Chaetoceros*), particulate matter and "marine snow" particles, instead of a gradual aggregation of "marine snow" as hypothesized by Herndl (1992).

Once large quantities of sticky material are present in water, different factors, mainly physical, are active in concentrating or dispersing the mucilaginous particles. Aggregate formation and accumulation appeared to be favored by increased stability of the water column and reduced water exchange with the mid-Adriatic region. Low shear forces and pycnocline layer formation have been indicated as important factors favoring the formation and persistence of large aggregates, essential to the marine snow and aggregating, growing diatom hypotheses (Herndl, 1992; Degobbi et al., 1995).

### Triggering factors

The mechanisms directly responsible for this phenomenon have not been conclusively identified although there have been special workshops convened and several international efforts are currently underway to explain mucilage formation in the basin. Two types of trigger mechanisms are important in explaining basin "mare sporco", those controlling initial production of the mucilaginous material, and those controlling aggregate formation and the extent and evolution of the phenomenon, once induced. In all possible explanations, mucilage production is initially attributable to unicellular algae. Forti (1906) and Zanon (1931) believed benthic diatom exudation produced the mucilage. Currently, the most popular opinion is the hyperproduction of polysaccharides from the several pelagic diatoms (Degobbi et al., 1995). Justification for unicellular algal production is derived from a suite of unrelated observations. A common thread, however, is that environmental conditions induce large exopolysaccharide production by phytoplankton, especially diatom species, and these are the probable primary causes of mucilage events. Degobbi et al. (1995) suggest that hyperproduction of polysaccharide exudates appears related to pulsing of freshwater inputs, in particular from the Po River

(Degobbis et al., 1995). The sequence of freshwater inputs and subsequent recycling appear to select for specific plankton communities with some species benefitting from short-term nutrient input and, following nutrient depletion, producing large amounts of polysaccharidic material. Experimental results support environmental control of exudates as indicated by stimulation of exudate production by a high N/P ratio coupled with low nutrient concentration (Lewin, 1955; Jones and Stewart, 1969; Myklestad and Haug, 1972; Myklestad, 1977; Monti et al., 1995b; Welker and Monti, 1995).

### Environmental consequences

These large, basin-wide mucilage events have large and significant impacts on plankton, nekton and benthic communities. Within the plankton, microzooplankton appeared to be most affected, with high incorporation in aggregates (Milani and Fonda-Umani, 1992). Some commonly observed mesozooplankton taxa, such as June-July swarming *Penilia avirostris*, were completely absent during the period dominated by the mucilage aggregates (Fonda-Umani, 1992). Its absence as well as the overall decline of the entire grazer community (Cataletto et al., 1996) has been attributed to grazer inability to utilize phytoplankton embedded in the mucoid matrix (Bochdansky and Herndl, 1992). However, within one month of the disappearance of the floating masses, typical summer plankton community abundance and structure returned (Fonda-Umani, 1992). Eventually, some portion of the floating mucilage was advected to southwestern regions of the basin, where it settled, seriously affecting organisms living on the seabed (Herndl, 1992), especially coelenterates and crustaceans. Large numbers of bivalve molluscs were killed by mucilage blocking of inhalant siphons. Further, eggs and larvae of a number of fish species living on the seabed were also probably affected (Rinaldi et al., 1995). In contrast to the effects on the benthic macrofauna, which were perturbed by the mucus, the mucilage aggregates, settled on the bottom, apparently stimulated the community. The presence of a dense community in 1991 might be explained by a combination of adequate conditions related to the presence of mucous aggregates, including a more undisturbed substratum caused by the interruption of dredging, decreased grazing pressure due to declined filtering capacity of epifauna, and nutrient-rich sediment for extra nutrient disposal remineralized at the mucus-sediment interface (Welker and Nichetto, 1996).

### Conclusions

Dinoflagellate blooms are related in all the cases to "new" nutrient inputs, mainly due to Po River and secondarily to minor coastal rivers along Emilia Romagna coasts as well as to river inputs (i.e. Isonzo) in the other northern areas affected dramatically by the same nuisance blooms. Frontal systems confined river inputs in a narrow coastal belt, limiting the effect of Po River inputs to inshore areas. Nutrient loads reach the open northern basin only during spring and autumn freshets causing seasonal diatom blooms (Franco and Michelato, 1992). Strong stabilization of water column during the whole warm season prevent from regenerated nutrient upwelling in euphotic zone. Few cases of reingression in surface layer of bottom waters could sustain blooms already started but

are insufficient to induce them (Vollenweider et al., 1992). Meteorological conditions play a fundamental role in enhancing river inputs through precipitations on the whole catchment-basin (i.e. Po Valley) and assuring calm sea during anticyclonic conditions (Galliani et al., 1992). This general features of the Adriatic system can show great variations due to its year to year variability (Fonda-Umani, 1991; Fonda-Umani et al., 1990; Baranovic et al., 1993) which affects oceanographic properties as well as plankton dynamics. Nevertheless it is possible to identify some main patterns:

1) two cyclical oscillations in abundance (with 5.5 and 7.3 year periodicity respectively) mainly related to physical factors and a long term trend of increase until the mid eighties due to eutrophication (Baranovic et al., 1993).

2) a strong increase in  $\text{NO}_3/\text{N}$  in the latter years in Po River inputs as well as in coastal sea waters (Rinaldi et al., in press).

3) a slightly decrease or at least no increase in  $\text{PO}_4/\text{P}$  which determines an increase of N/P ratio (Rinaldi et al., in press). In northern Adriatic N/P ratios are usually very high (ranging between 30 and 80), showing annual oscillations with maxima values in winter and spring, lowering in summer to rise again in autumn (Innamorati and Giovanardi, 1992). In the latter years N/P ratio increase due to N increase and could have enhanced polysaccharidic hyperproduction by diatoms:

4) an increase of temperature values both in seasonal minima and maxima (Malej and Fonda-Umani, in press) depending on meteorological evolutions typifying the latter years, characterized by long period of high pressure due to persistence of anticyclonic conditions.

5) a general decrease of phytoplankton biomass as chlorophyll values (Malej and Fonda-Umani, in press) and a shift from larger size phytoplankton to small size phytoplankton, which indicates a more oligotrophic and less hydrodynamic situation (Smayda, 1970; Malone, 1980), than in the previous years (Fonda-Umani et al., 1995).

6) an increase of consumer (netzooplankton) biomass in the same period (Malej and Fonda-Umani, in press) which could have contribute to lower phytoplankton biomass through grazing impact.

In some cases the effect on the coastal system of the remedials adopted to reduce the impact of waste discharge is also evident. In particular, in the Bay of Muggia, a small confined bay in the Gulf of Trieste where in the past the phytoplankton abundance reached more than  $14 \cdot 10^6 \text{L}^{-1}$  (Fonda-Umani et al., 1982) and red tides were often recorded, the starting up of a waste treatment with an underwater pipe discharging outside the Bay lead to a decrease of phytoplankton which now exceptionally reaches values of  $1.5 \cdot 10^6 \text{L}^{-1}$ .

The harmful blooms characterizing the seventies and the early eighties appear related to a widespread increase in the general trophism of the system (Fonda-Umani, 1991; Baranovic et al., 1993). This increase appeared to be due to combined effects of a series of factors among which water exchange with the Mediterranean, climatic factors, particularly temperature and atmospheric pressure, and eutrophication are the most important (Baranovic et al., 1993).

The same physical factors seem to cause the appearance of large aggregates. In particular Degobbi et al. (1995) suggest that climatic changes during the eighties, modifying oceanographic conditions and hydrological patterns might have influenced the dynamic of nutrient inputs and recycling mechanisms resulting in a selection of plankton communities.

## References

- ANDERSON D.M., 1989. Toxic algal blooms and red tides: A global perspective, in *Red Tides. Biology, Environmental Science and Toxicology*, edited by T. Okaichi, D.M. Anderson and T. Nemoto, pp. 11-16, Elsevier, NY.
- ARTEGIANI A., R. AZZOLINI, M. MARZOCCHI, M. MORBIDONI, A. SOLAZZI AND F. CAVOLO, 1985. Prime osservazioni su un "bloom" fitoplanctonico lungo la costa marchigiana nell'anno 1984, *Nova Thalassia*, 7(3), 137-142.
- BARANOVIC A., M. SOLIC, T. VUCETIC AND N. KRSTULOVIC, 1993. Temporal fluctuations of zooplankton and bacteria in the middle Adriatic Sea, *Mar. Ecol. Progr. Series*, 92, 65-75.
- BIANCHI F., A. COMASCHI SCARAMUZZA, A. LOMBARDO AND G. SOCAL, 1982. Note sulla presenza di *Noctiluca scintillans* (Macarteny) nel Golfo di Venezia. Aprile 1980. *Ist. Veneto Sci Lett. Arti. Rapp. Studi*, 8, 121-132.
- BOCHDANSKY A.B. AND G.J. HERNDL, 1992. Ecology of amorphous aggregations (marine snow) in the Northern Adriatic Sea. III. Zooplankton interactions with marine snow, *Mar. Ecol. Progr. Series*, 87, 135-146.
- BONI L., 1983. Red tides of the coast of Emilia Romagna (north-western Adriatic sea) from 1975 to 1982, *Inf. Bot. Ital.*, 15, 18-24.
- BONI L., M. POMPEI AND M. RETI, 1983. The occurrence of *Gonyaulax tamarensis* Lebour bloom in the Adriatic Sea along the coast of Emilia Romagna, *Giorn. Bot. Italiano*, 117 (3/4), 115-120.
- CACCIAMANI C., S. NANNI, F. NUCCIOTTI, AND T. PACCAGNELLE, 1992. Analysis of meteorological parameters relating to Adriatic eutrophication, *Marine Coastal Eutrophication*, edited by R.A. Vollenweider, R. Marchetti, and R. Viviani, *Science of the Total Environment, Elsevier Science Publ. (suppl.)*, pp.159-170.
- CANADIJA S., 1951. Cvjetanje mora, *Ribarski godisnjak*, 180-182.
- CASSINARI E., D. GRILLO, M. PRINCI, M. SPECCHI, F. STRAVISI AND G. VALLI, 1979. Osservazioni su *Noctiluca miliaris* SURIRAY del Golfo di Trieste, *Atti Conv. Sc. Naz. P.F. Oceanografia e Fondi Marini*, Roma, marzo 1979, 1-8.
- CATALETO B., E. FEOLI, S. FONDA-UMANI, M. MONTI AND I. PECCHIAR, 1996. Analyses of the Relationships Between Mucous Aggregates and Phytoplankton Communities in the Gulf of Trieste (North Adriatic Sea) by Multivariate Techniques, *P.S.Z.N. I Marine Ecology*, 17(1-3), 291-308.
- CULLEN J.J. M. ZHU, R.F. DAVIS, AND D.C. PIERSON, 1985. Vertical migration, carbohydrate synthesis and nocturnal nitrate uptake during growth of *Heterocapsa niei* in a laboratory water column, in *Toxic Dinoflagellates*, edited by D.M. Anderson, A.W. White and D.G. Baden, pp. 189-194.
- DEGOBBIS D., S. FONDA-UMANI, P. FRANCO. A. MALEJ, R. PRECALI AND N. SMODLAKA, 1995. Changes in Northern Adriatic Ecosystem and appearance of hypertrophic gelatinous aggregates, *Science of the Total Environment. Elsevier Science Publ.*, 165, 43-58.
- DELLA TORRE TASSIS L., 1748. Notizie sulla vasta fioritura algale (diatomee "cosa moccichiosa") dell'anno 1729, *Raccolta d'opuscoli scientifici e filologici*, 34.
- DE TONI G.G., 1891. Il curioso fenomeno della poltiglia in mare-il mare sporco, *La Venezia 17 e 18 agosto 1891*.
- FONDA-UMANI S., 1990. Pelagic ecosystem in the Gulf of Trieste: last variations, *Symp. "Die obere Adria"*, Graz, 27 April 1990, A 1-13.

- FONDA-UMANI S., 1991. General features of the planktonic system in the Gulf of Trieste and their variations in the last decade, *MAP Tech. Rep.*, s. 47, 82-101.
- FONDA-UMANI S., 1992. Successioni fito, micro e mesozooplantoniche nell'Alto Adriatico, in *Atti V Convegno SITE*, edited by R. Marchetti and M. Cotta Ramusino, pp.221-246.
- FONDA-UMANI S., M. PRINCI, M., SPECCHI AND L. MILANI, 1982. Influenza di fattori ambientali locali sulla comunità planctonica del Golfo di Trieste, *Boll. Mus. Ist. Biol. Univ. Genova*, 50 (suppl.), 188-193.
- FONDA-UMANI S., M. PRINCI AND M., SPECCHI, 1983. Note ecologiche su *Noctiluca miliaris* SURIRAY del Golfo di Trieste (Alto Adriatico), *Atti Mus. Civ. Sc. Nat. Trieste*, 35, 259-265.
- FONDA-UMANI S., G. HONSEL, M. CABRINI AND L. MILANI, 1985. A Tintinnid "bloom" in the Gulf of Trieste (North Adriatic Sea), *Oebalia*, 11, 149-156.
- FONDA-UMANI S., E. GHIRARDELLI AND M. SPECCHI, 1989. Gli episodi di "mare sporco" nell'Adriatico dal 1729 ai giorni nostri, *Regione Autonoma Friuli-Venezia Giulia, Dir. Reg. Ambiente*, p. 178.
- FONDA-UMANI S., P. FRANCO, E. GHIRARDELLI AND A. MALEJ, 1990. Outline of oceanography and the plankton of the Adriatic Sea, *The Adriatic Sea, Papers presented at the 25th European Marine Biology Symposium*, University of Ferrara, pp.25-43.
- FONDA-UMANI S., S.C. YONG, E. FEOLI, B. CATALETTO, M. CABRINI AND L. MILANI, 1995. Is it possible to identify any plankton succession in the Gulf of Trieste (Northern Adriatic Sea)?, in *Proceedings of the 28th EMBS*, 59-65.
- FORTI A., 1906. Alcune osservazioni sul "mare sporco" ed in particolare sul fenomeno avvenuto nel 1905, *Nuovo Giornale Botanico Italiano* (N. S.), 13(4), 1-56.
- FRANCO P., 1973. L'influenza del Po sui caratteri oceanografici e sulla distribuzione della biomassa fitoplanctonica nell'Adriatico Settentrionale, *Ann. Univ. Ferrara*, NS., 95-117.
- FRANCO P. AND A. MICHELATO, 1992. Northern Adriatic Sea: Oceanography of the basin proper and of the western coastal zone, in *Marine Coastal Eutrophication*, edited by R.A. Vollenweider, R. Marchetti, and R. Viviani, pp.36-52, Elsevier, NY.
- GALLIANI G., F. FILIPPINI, G. MONTANARI, A. RINALDI AND R.A. VOLLENWEIDER, 1992. Time series analysis of coenological parameters measured at a fixed station, *Marine Coastal Eutrophication*, edited by R.A. Vollenweider, R. Marchetti, and R. Viviani, *Science of the Total Environment, Elsevier Science Publ. (suppl.)*, pp. 171-186.
- HERNDL G.J., 1992. Marine snow in the Northern Adriatic Sea: possible causes and consequences for a shallow ecosystem, *Mar. Microb. Food Webs*, 6(2), 149-172.
- INNAMORATI M. AND F. GIOVANARDI, 1992. Interrelationships between phytoplankton biomass and nutrients in the eutrophicated areas of the North-Western Adriatic Sea, *Marine Coastal Eutrophication*, edited by R.A. Vollenweider, R. Marchetti and R. Viviani, *Science of the Total Environment, Elsevier Science Publ. (suppl.)*, pp. 235-250.
- JONES K. AND W.D.P. STEWART, 1969. Nitrogen turnover in marine and brackish habitats. III. The production of extracellular nitrogen by *Calothrix scopulorum*, *Journ. Mar. Biol. Ass. U.K.*, 49, 475-488.
- LEWIN J.C., 1955. The capsule of the diatom *Navicula pellucida*, *J. Gen. Microbiol.*, 13, 162-169.
- MALEJ A., 1983. *Noctiluca miliaris* SURIRAY red tide in the Gulf of Trieste, *Thalassia Jugosl.*, 19(1-4), 261-269.
- MALEJ A. AND S. FONDA-UMANI, in press. Evoluzione delle interazioni trofiche nell'ecosistema del Golfo di Trieste, *Atti Convegno "Evoluzione dello stato trofico in*

- Adriatico: analisi degli interventi attuati e future linee di intervento*", Marina di Ravenna, 28-29 settembre 1995.
- MALONE T.C., 1980. Algal size, in *The Physiological Ecology of Phytoplankton*, edited by I. Morris, pp. 433-463.
- MANCINI L., R. POLETTI, AND G. SANSONI, 1980. Evoluzione dei processi eutrofici nell'Adriatico Emiliano Romagnolo e considerazioni in rapporto alla pesca costiera, *Pub. Cons. Centro Univ. Studi e Ricerche sulle Risorse marine*. Cesenatico, p. 11.
- MILANI L. AND FONDA-UMANI S., 1992. Mucilaginous agglomerations in the Gulf of Trieste (Northern Adriatic Sea): analysis of the micro-zooplankton populations in the period June-August 1989, *Marine Coastal Eutrophication*, edited by R.A. Vollenweider, R. Marchetti, and R. Viviani, *Science of the Total Environment, Elsevier Science Publ. (suppl.)*, pp. 569-580.
- MONTANARI G., AND A. RINALDI, 1983. Eutrofizzazione delle acque costiere della regione Emilia Romagna, *Acqua-Aria*, 2, 123-128.
- MONTI M., C. WELKER, G. DELLAVALLE, L. CASARETTO AND S. FONDA-UMANI, 1995(a). Mucous aggregates under natural and laboratory conditions: a review, *Science of the Total Environment, Elsevier Science Publ.*, 165, 145-154.
- MONTI M., C. WELKER AND S. FONDA-UMANI, 1995(b). Organic carbon particulate analyses in three marine diatoms under controlled conditions, *Giornale Botanico Italiano*, 128(6), 47-50.
- MYKLESTAD S., 1977. Production of carbohydrates by marine planktonic diatoms. II. Influence of the N/P ratio in the growth medium on the assimilation ratio, growth rate, and production of cellular and extracellular carbohydrates by *Chaetoceros affinis* var. *willei* (Gran) Hustedt and *Skeletonema costatum* (Grev.) Cleve, *J. Exp. Mar. Biol. Ecol.*, 29, 161-179.
- MYKLESTAD S. AND A. HAUG, 1972. Production of carbohydrates by the marine diatom *Chaetoceros affinis* var. *willei* (Gran) Hustedt. I. Effect of the concentration of nutrients in the culture medium, *J. Exp. Mar. Biol. Ecol.*, 9, 125-136.
- PUCHER-PETKOVIC T. AND I. MARASOVIC, 1987. Contribution a la Connaissance d'une Pousse Extraordinaire d'Algues Unicellulaires (Adriatique Septentrionale), *CENTRO*, 1(3), 33-44.
- REVELANTE N. AND M. GILMARTIN, 1991. The phytoplankton composition and population enrichment in gelatinous "macroaggregates" in the northern Adriatic during the summer of 1989, *J. Exp. Mar. Ecol.*, 146, 217-233.
- RINALDI A., R.A. VOLLENWEIDER, G. MONTANARI, C.R. FERRARI AND A. GHETTI, 1995. Mucilages in Italian seas: the Adriatic and Tyrrhenian Seas, 1988-1991, *Science of the Total Environment, Elsevier Science Publ.*, 165, 165-184.
- RINALDI A., G. MONTANARI, C.R. FERRARI AND A. GHETTI, in press. Evoluzione dello stato trofico delle acque costiere emiliano - romagnole nel periodo 1982-1993, Atti Convegno "Evoluzione dello stato trofico dell'Adriatico: analisi degli interventi attuati a future linee di intervento", Marina di Ravenna, 28-29 settembre 1995.
- SMAYDA T.J., 1970. The suspension and sinking of phytoplankton in the Sea, *Oceanogr. mar. Biol.a. Rev.*, 8, 353-414.
- SMAYDA T.J., 1990. Novel and nuisance phytoplankton blooms in the sea: Evidence for a global epidemic, in *Toxic Marine Phytoplankton*, edited by E. Granéli, B. Sundstrom, L. Edler and D.M. Anderson, pp. 29-40, Elsevier, NY.
- STACHOWITSCH M., N. FANUKO AND M. RICHTER, 1990. Mucus aggregates in the Adriatic Sea: an overview of stages and occurrence, *PSZNI Mar. Ecol.*, 11(4), 327-350.

- DESYRSKI S.A., 1872. Sulle masse glutinose osservate nei mesi di giugno e luglio 1872 nella parte settentrionale dell'Adriatico. *Relazione prodotta all'I.R. Governo Marittimo di Trieste, Tip. Hermanstofer Trieste*, 15-17.
- VIVIANI R., 1983. Le diverse fioriture di fitoplancton dal 1978 al 1982, nell'area del mare Adriatico settentrionale prospiciente la costa Emiliana-Romagnola, *Eutrofizzazione dell'Adriatico. Ricerche e linee d'intervento. Reg. Emilia Romagna*, 79-97.
- VOLLENWEIDER R.A., A. RINALDI AND G. MONTANARI, 1992. Eutrophication, structure and dynamics of a marine coastal system: results of ten-year monitoring along the Emilia-Romagna coast (Northwest Adriatic Sea), in *Marine Coastal Eutrophication*, edited by R.A. Vollenweider, R. Marchetti, and R. Viviani, *Science of the Total Environment, Elsevier Science Publ. (suppl.)*, 63-106.
- WELKER C. AND M. MONTI, 1995. Polysaccharidic flocculation from the marine diatom *Cylindrotheca closterium* (Ehr.) Reimann & Lewin under nutrient starvation. *Giornale Botanico Italiano*, 128(6), 44-46.
- WELKER C. AND P. NICETTO, 1996. The Influence of Mucous Aggregates on the Microphytobenthic Community in the Northern Adriatic Sea, *P.S.Z.N. I Marine Ecology*, 17(1-3), 473-489.
- ZANON D.V., 1931. Esame di un campione di "mare sporco" del Golfo di Fiume, *Mem. Pont. Acad. Lincei*, 15, 1-33.