THE APPLICATION OF SEAWATCH INDONESIA MONITORING SYSTEM IN DETERMINING THE MICROBIAL NUTRIENT CYCLING AND THE PRIMARY PRODUCTIVITY IN THE INDONESIAN MARINE HABITATS TO SUPPORT THE FISHERY PRODUCTION IN INDONESIA

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Abstract

The existence of life in the marine environment is dependent upon the continual release of fresh supplies of essential nutrients. Greatest attention was focused on the cycling of nitrogen, sulfur, carbon and phosphorus. The role of these elements in life-giving processes is well established. For example, nitrogen is necessary for amino acids, nucleic acids and amino sugars; sulfur is essential in the sulfhydryl groups (-SH) of amino acids and their polymers; carbon is the prime substance of all organic compounds; and phosphorus is contained in nucleic acids, phosphate asters, sugar phosphates, phosphates, and ATP. The marine microorganisms have significant roles in cycling processes of these nutrients as well as the primary producers in marine ecosystems. In Fact, the primary productivity in marine habitats is very important, i.e. 40% of the total plant primary productivity on earth is performed by marine phytoplankton.

SEAWATCH Indonesia Monitoring System can be applied in determining the cycling of such essential nutrients and the conditions of phytoplankton, which is very important for the primary productivity in the Indonesian marine environment. It is expected that by knowing the conditions of phytoplankton and nutrient cycling in Indonesian waters, the fishery resources of certain water's ran be estimated and can more optimally be managed to increase the income of people in Indonesia.

I. INTRODUCTION

The existence of life in the marine environment is dependent upon the continual release of fresh supplies of essential nutrients. Organic material (carbon) will be mineralized, yielding products, which are essential for dissimolatory and assimilatory processes. In pelagic waters recycling of minerals is a slow process, but greater rates of activity occur in sediments and in coastal waters. According to Jorgensen (1980) the cycling of elements is regulated by two main processes, namely the assimilation of inorganic nutrients by photosynthetic organisms, and the subsequent mineralization by heterotrops.

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The pelagic marine habitat is a unique environment for both macro- and microorganisms (Isaacs, 1969). It completely lacks higher plants, all primary production is carried out by microscopic algae and bacteria. Microbial numbers are relatively high in near shore, upwelling, and estuarine waters, but sink as low as 1-100 per ml in pelagic waters (ZoBell, 1946; Oppenheimer, 1963; Kriss et aL, 1967; Wood, 1967; Kad & Holm-Hansen, 1978). Here, heterotrophic bacteria tend to be associated with algal surfaces or detrital particles, which offer a nutritional advantage compared to the extremely low concentrations of dissolved organic nutrients in the pelagic sea water. Relatively high numbers of microorganisms occur in the first few centimeters of most marine sediments (107-108/g), but the numbers tapped off in deeper sediment layers (Kad, 1978). The reason seems to be the anaerobic conditions. The highest biomass of microorganisms in marine waters is normally near the surface and decreases with depth.

II. THE MARINE MICROBIAL NUTRIENT CYCLING

a. The Carbon Cycle

In sea water there are 34,500 billion tons of carbon, the cycling of which is in a steady state (Hobbie & Melillo, 1984). Carbon transfer through food webs is summarized in Figure 1, whereas carbon flow through marine anaerobic sediments is represented in Figure 2. Carbon dioxide fixation to form organic molecules occur in autotrophs, i.e. algae, cyanobacteria, and green and purple photosynthetic bacteria. Conversely methanogens reduce carbon dioxide anaerobically to form methane, which is in turn used by comparatively few organisms. Heterotrophs complete the carbon cycle by generating carbon dioxide through the respiration activity.

Marine algae supply an essential input of carbon to the marine ecosystems (Taylor, 1957; Boney, 1966; Dawes, 1974). The main algae include members of Chlorophycophyta, Euglenophycophyta, Phaeophycophyta, Chrysophycophyta, Cryptophycophyta, Phyrrhophycophyta, and Rhodophycophyta. Most Phaeo-phycophyta, or brown algae, which are conspicuous intertidal component extending from the upper littoral zone to depths, greater than 220 m in clear tropical waters. Additionally, members of Chlorophycophyta and Chrysophy-cophyta are prominent members of plankton. Marine plankton is found in maximal concentrations in the upper region of the ocean, usually at 0-50 m in depth (ZoBell, 1946; Holm-Hansen, 1969). In very clear tropical waters, due to the light intensity, the phytoplankton maximum is not found at the surface but at 10-15 m of depth, green algae are found in greater number near the surface, usually disappearing below 30 m, while red algae and golden brown algae occur at somewhat greater depth.

b. The Nitrogen Cycle

The biogeochemical cycling of the element nitrogen is highly dependent on the activities of microorganisms. Figure 3 shows a generalized scheme for the biogeochemical cycling of nitrogen. The critical steps of nitrogen fixation, nitrification, and denitdfication are all mediated by bacteria. Nitrogen enters the cycle as ammonia, resulting from the breakdown of proteins by a process Galled ammonification, and as nitrates, which are derived from fertilizers etc., and arrive in the sea via terrestrial runoff.

Because various environmental conditions favor specific nitrogen cycling processes, there is a spatial zonation of cycling process. Fixation of nitrogen occurs in both surface and subsurface habitats. Nitdfication occurs exclusively in aerobic habitats. Denitrification predominates in water-clogged soils and in anaerobic aquatic sediments. The cycling of nitrogen within a given habitat also exhibits seasonal fluctuations; during spring and fall blooms of cyanobacteria, for example, rates of nitrogen fixation in aquatic habitats usually are high, reflecting population fluctuations and availability of needed energy and mineral nutrients for fixation of molecular nitrogen.

In aquatic habitats, cyanobacteria are the principal nitrogen fixers (Raed, 1990). Many of the filamentous nitrogen-fixing cyanobacteria, such as Amabaena, Aphanizomenon, Nostoc, Gloeotrichia, Cylindrospermum, Calothrix, Scytonema, and Tolypothrix have heterocysts. Heterocysts are thick-walled, less pigmented, and often enlarged cells occurring at more-or-less regular intervals among the regular cells. Nitrogen fixation is localized in the heterocysts, where the oxygen-sensitive nitrogenase is protected from inactivation by the photosynthetically produced oxygen.

Some nonheterocystous cyanobacteria, such as Oscillatoria, Trichodesmium, Microcoleus, and Lyngbya have been shown to fix nitrogen. Apparently, nonheterocystous cyanobacteria possess mechanisms to reactivate or resynthetize their nitrogenase after oxygen exposure. For example, some of the nonheterocystous cyanobacteria show a temporal separation between photosynthesis and nitrogenase activities. Dudng daylight hours, photosynthesis and photosynthate storage take place, with little or no nitrogen fixation. During night time, in the absence of photosynthesis, nitrogen fixation takes place at the expense of the stored photosynthate. Other nonheterocystous nitrogen fixers form clumps or mats. In this aggregation, the outer cells photosynthesize, while the innermost cells, through a combination of shading and respiratory activity, are in a zone of reduced oxygen tension permissive of nitrogenase activity.

Rates of nitrogen fixation by cyanobacteria are generally one to two orders of magnitude higher than by free-living nonphotosynthetic soil bacteria. Nitrogen-fixing cyanobacteria, many of which form heterocysts, are found both in marine and freshwater habitats. Some nitrogen-fixing cyanobacteria form associations with other microorganisms, as in lichens; some form symbiotic associations with plans, such as the Azola-Anabaena associations; others are free-living.

Many plants, animals and microorganisms are capable of ammonification, a process in which organic nitrogen is converted to ammonia. Nitrogen in living and dead organic matter occurs predominantly in the reduced amino form. Blackburn

(1983) emphasized the importance of organic nitrogen mineralization for continued ecosystem productivity. In acidic to natural aqueous environments, ammonia exists as ammonium ions, while some of the ammonia produced by ammonification is released from alkaline environment to the atmosphere, where it is relatively inaccessible to biological systems. Ammonia and other forms of nitrogen within the atmo-ecosphere can be returned to the litho- and hydroecospheres by precipitation. The amount of ammonium nitrogen in global precipitation has been estimated at 38-85 million metric tons per annum (Sorderlund & Svensson, 1976).

In nitrification, ammonia or ammonium ions are oxidized to nitrite ions and then to nitrate ions. The process of nitrification appears to be limited for the most part to a restricted number of autotrophic bacteria (Focht & Verstraete, 1977; Hooper, 1990). Different microbial populations carry out the two steps of nitrification - that is, the formation of nitrite and the formation of nitrate. However, normally the two processes are closely coupled and an accumulation of nitrite does not occur. Nitrifying bacteria are chemolithotrophs and utilize the energy derived from the nitrifiction to assimilate C02-

The dominant genus that is capable of oxidizing ammonia to nitrite is Nitrosomonas, and the dominant genus capable of oxidizing nitrite to nitrate is Nitrobacter. Other bacteria capable of oxidizing ammonia to nitrite are found in the genera Nitrosospira, Nitrosococcus, Nitrosolobus, and Nitrosovibrio (Block et aL, 1990). In addition to Nitrobacter, members of the genera Nitrospira, Nitrospina, and Nitrococcus are able to oxidize nitrite to nitrate. Nitrobacter, Nitrospira, Nitrospina, Nitrococcus, Nitrosomonas, and Nitrosococcus occur in marine habitats. Nitrobacter, Nitromonas, Nitrospira, Nitrosococcus, and Nitrosolobus are found in soil habitats. Some other microorganisms, including heterotrophic bacteria and fungi are capable of limited oxidation of nitrogen compounds, but heterotrophic nitrification is very small and insignificant.

Nitrate ions can be incorporated by a variety of organisms into organic matter through assimilatory nitrate reduction. A heterogeneous group of microorganisms, including many bacterial, fungal, and algal species, is capable of assimilatory nitrate reduction. This process involves several enzyme systems, including nitrate and nitrite reductases, to form ammonia, which can be subsequently incorporated into amino acids (Goftschalk, 1979). The dissimilation of nitrate to gaseous nitrogen, via nitric oxide (NO) and nitrous oxide, involves at least three separate enzymes. Stoichiometrically denitrification may be expressed as:

$$5\ C_6H_{12}O_6 + 24\ NO_3^- + 24\ H^+ \text{ -----}\rightarrow 30\ CO_2 + 12\ N_2 + 42\ H_2O$$

Organisms that carry out the reaction include the majority of marine aerobic and facultatively anaerobic heterotrpophic bacteria together with many algae and fungi. The dissimilation to nitrite may also involve sulfate-reducing bacteria. In marine sediments there is a constant accumulation of ferrous ions (Fe^{2+}) following the reduction of ferric (Fe^{3+}) compounds, shortly after the depletion of endogenous nitrates (Sorensen, 1982). It is considered that the process occurs as a result of activity by facultatively anaerobic nitrate reducers.

Marine picoplankton, namely cyanobacteria, are capable of utilizing nitrate, ammonium compounds and/or urea as the sole source of nitrogen for growth (Probyn,

1985; Probyn & Painting, 1985). In particular, picoplankton are responsible for the uptake of the majority (90%) of nitrogen accounted for by phytoplankton in the oceanic environment (Stockner & Antia, 1986). It appears that the major pathway of inorganic nitrogen assimilation by chroococcoid cyanobacteria is nitrate to nitrite, and then to ammonium, glutamine and finally to glutamic acid (Syreft, 1981).

There are two types of dissimilatory nitrate reduction. A Variety of facultatively anaerobic bacteria including Alcaligenes, Escherichia, Aeromonas, Enterobactefia, Bacillus, Flavobacterium, Nocardia, Spitillum, Staphylococcus, and Vibrio, reduce nitrate under anaerobic conditions to nitrite. These organisms do not produce gaseous nitrogen products, that is, they do not denitrify. As compared to denitrification, nitrate ammonification performed by these organisms is an environmentally less significant process for the reductive removal of nitrate and nitrite ions.

Denitrifying nitrate reducers such as Paracoccus denitrificans, Thiobacillus denitfificans and various pseudomonads have a more complete reduction pathway, converting nitrate through nitrite to nitric oxide (NO), and nitrous oxide (N20) to molecular nitrogen. The denitrification sequence is as follows:

NO_3^- ---→ NO_2^- ---→ NO ---→ N_2O ---→ N_2

The proportion of the denitrification products is dependent both on the denitrifying microorganisms and on environmental conditions. The lower the pH of the habitat, the greater the proportions of nitrous oxide formed. Formation of molecular nitrogen is favored by an adequate supply or an oversupply of reducing equivalents.

Denitrification occurs under strictly anaerobic conditions or under conditions of reduced oxygen tension. Some denitrification may occur in generally aerobic environments if these contain anoxic microhabitats (Hutchinson & Mosier, 1979). Denitrification is more common in standing waters than in running streams and rivers. Denitrification rates typically are higher in the hypolimnion of eutropic lakes during summer and winter stratification than during fall and spring turnover.

c. The Sulfur Cycle

Sulfate is the second most abundant anion in sea water, and the SO_4^{2-} of the marine environment represents a large, slowly cycled sulfur reservoir. Plants, algae and many heterotrophic microorganisms assimilate sulfur in the form of sulfate. For incorporation into cysteine, methionine, and coenzymes in the form of sulfhydryl (-SH) groups, sulfate needs to be reduced to the sulfide level by assimilatory sulfate reduction. A direct uptake as sulfide is not feasible for most microorganisms because of the high toxicity of H2S- In assimilatory sulfate reduction, toxicity is avoided by immediately reacting the reduced sulfur with an acceptor - for example, serine - to yield cysteine.

In the marine environment, a major decomposition product of organosulfur is dimethylsulfide (DMS). Dimethylsulfide is released during zooplankton grazing on phytoplankton and also during decay processes (Dacey & Wakeham, 1986). The volatile DMS escapes the oceans; according to some estimation, 90% of the total

sulfur flux from the marine environment to the atmosphere occurs in the form of DMS. Another major product is H2S- Once they escape to the atmosphere, DMS, H2S, and mercaptans are subject to photooxidative reactions that ultimately yield sulfate. If H2S does escape to the atmosphere, it may be phototrophically oxidized under anaerobic conditions.

d. The Phosphorus Cycle

Phosphorus is not an abundant compound of the ecosphere (Cosgrove, 1977; Ehrlich, 1981). Large. slowly cycled reservoirs of phosphates occur in marine and other aquatic sediments, while small and actively cycled reservoirs of phosphate are dissolved phosphate in soils and waters and phosphate in living and dead organic matter.

Although phosphate is normally not reduced by microorganisms, it appears that some soil and sediment microorganisms may be capable of utilizing phosphate as a terminal electron acceptor under appropriate environmental conditions. Phosphate is likely to serve as a terminal electron acceptor in the absence of sulfate, nitrate, and oxygen.

Productivity in many habitats is phosphate limited. In aquatic environments, phosphate concentrations exhibit seasonal fluctuations that are associated with algal and cyanobacterial blooms. The precipitation of phosphorous, especially in marine habitats, greatly limits primary productivity. In aquatic habitats, phosphorous may exist in soluble or particulate forms. These forms exhibit differential reactivity and availability to the biological community (Chapra & Robertson, 1977).

III. THE MARINE PRIMARY PRODUCTIVITY

The role of green terrestrial plants as the saviors of animal life on earth would seem undisputed. Yet of the total estimated plant primary productivity, i.e. 1.4 x 1014 kg dry wt/year, 40% is derived from the activity of marine phytoplankton, of which the role of algal picoplankton (size range of 0.2 - 2.0 μm) is of overwhelming importance (Sherr & Sherr, 1984; Stocker & Antia, 1986). In fact, the hourly carbon production rates for marine picoplankton have been calculated to be in the range of 0.0004 mg c/m3 (Saijo & Takesue, 1965) to > 31 mg c/m3 (Glover et al., 1985b) (Table 1). These quantities correspond to 0.1-90% of the total carbon production in the marine environment, with higher values recorded to oligotrophic areas of the open ocean. Moreover primary productivity has been noted to increase with depth into the euphotic zone (Li et al., 1983; Platt et al., 1983; Glover et aL, 1985a,b) which partially reflects a greater efficiency of the photosynthetic pigments to utilize blue green light. According to data published by Woodwell (1970), net primary productivity for oceanic, coastal and upwelled sea water is 100, 200, and 600 respectively. Here, the relative importance of upwelling areas in marine primary productivity is clearly demonstrated.

Overall it is considered that algae, i.e. diatoms, dominate by contributing 20-25% of the world's net primary productivity. However, the importance of cyanobacteria should not be overlooked, with one genus, Synechococcus responsible for 10% of the total marine primary productivity (Waterbury et aL, 1979). These

numbers of the phytoplankton community are especially abundant in the neuston. Thus C02 fixation with the production of organic molecules results from the activity of autotrophs, namely algae (diatoms) and cyanobacteria and also from the activity of green and purple photosynthetic bacteria.

Bacterial productivity measurements have been the focus of intense interest. For example, Turley & Lochte (1985) observed that, during summer in the Irish Sea, bacterial productivity was greater in the waters above the thermohaline than below it. Thus at 4 and 60 m depth, bacterial productivity was determined to be 12.7 μg C/l/day (generation time = 0.9 day) and 3.0 μg C/l/day (generation time = 20 days), respectively. Moriarty et al. (1985) estimated bacterial production as 120-370 mg c/m2 /day during summer in water over a coral reef flat; this amount equated to 30-40% of the primary productivity by benthic microalgae. During winter, productivity was only 20% of the value for summer. Within sediments bacterial productivity was estimated as 180_190 Mg CflM2/day (Moriarty at aL, 1986) as measured by the rate of tritiated thymidine incorporation into DNA, and the rate of 32 p incorporation into phospholipid. Significantly most bacterial production occurred in the top 20 mm layer of sediment, which was the zone of greatest root and rhizome biomass. Additionally, seagrasses are considered to be major primary producers in shallow coastal temperate and tropical regions. In the study by Moriarty et aL (1986), 6-17% of fixed carbon was exuded from seagrasses into the sediment. Thus the high value of bacterial productivity was attributed to exudation as well as root decomposition.

Generally, it would appear that habitats which are capable of retaining nutrients, e.g. coral reefs, are able to maintain high level of productivity, even if the surrounding environment is oligotrophic, i.e. nutrient-limited or poor. Conversely, systems with low capacities to retain essential nutrients, e.g. epipelagic habitats, demonstrate low nutrient-limited rates of primary productivity, even if light and temperature conditions favor high productivity (Odum, 1983).

IV. THE APPLICATION OF SEAWATCH INDONESIA MONITORING SYSTEM

The SEAWATCH Indonesia Monitoring System utilizes several sensors on the buoys to measure meteorological and oceanographic parameters, one of them is a sensor to determine the attenuation coefficient to monitor algal blooms. This sensor can also be used to know the conditions of phytoplankton in marine habitats.

The conditions of phytoplankton are closely related to the primary productivity of certain waters, hence can be employed as an indicator of fish resources in such waters. The conventional observation will not be able to analyze accurately about the primary productivity of certain waters, because the data utilized are usually very limited, while on the other hand the development of phytoplankton as primary producers fluctuates. The employment of data from buoys will give continuous results approaching the real condition. Beside pigment data it also provide data of nutrients, current, and other hydrological data to reach to a conclusion which approaches the conditions of water being observed.

Among phytoplankton species, there are species that can cause problems, either for fisheries or human health. For example, there is massive death of fish or

other marine biota that is caused by toxins excreted by certain phytoplankton species. Fish cultured in floating nets in sea water will suffer if there is a blooming of this toxic phytoplankton species. This blooming is known as red tide. Actually the toxin excreted by such phytoplankter is not always causing troubles for fish or other marine biota, but it only accumulate in their bodies. However, if such fish and marine biota are eaten by human, then it is the human who will suffer with a possibility of death.

Research conducted by the Research and Development Center for Oceanology of the Indonesian Institute of Sciences has found about 31 phytoplankton species having potentials for causing problems for fish and human health (Praseno, 1998). Yet, until now it is still difficult to predict when and where red tides will happen, considering that data collection is still performed conventionally. Therefore, the buoy data will be very helpful in monitoring the phytoplankton development of certain waters and provide early warning if red tides occur. Hence, the fish products can become one of the primary commodity for Indonesia and negative impacts on human being can be prevented.

V. CONCLUSION

In conclusion, it is expected that the SEAWATCH Indonesia Monitoring System can be applied more optimally in supporting research and observation on the marine natural resources, so that the abundant natural resources in Indonesian waters can be utilized maximally to increase the income and welfare of Indonesian people who are still in the monetary crisis until now.

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APPENDICES

Sampling Site	Fraction Size (μm)	Production Rate ($mgC/m^3/h$)	% of Total Production
Atlantic Ocean			
Nova Scotia Shelf	0.2 – 1.0	1.8 – 5.8	12 – 65
Arctic	0.2 – 1.0	0.12 – 2.0	10 – 25
North West	0.2 – 1.0	0.0004 – 0.65	0.1 – 66
Sargasso Sea	0.2 – 3.0	3.1 – 31.0	60 – 80
Equatorial	0.45 – 3.0	1.08	20
Tropical	0.4 – 1.0	0.5	50 – 60
Indian Ocean			
South China Sea	0.45 – 0.8	0.01 – 0.08	1 – 22
South Chine Sea	0.8 – 5.0	0.02 – 0.16	9 – 40
Pacific Ocean			
Tropical	0.2 – 1.0	0.2 – 45	20 – 80
Subtropical	0.2 – 3.0	0.75 – 1.5	70
Subtropical	0.45 – 5.0	7.6	83
Coastal California	0.2 – 5.0	1.29 – 2.19	75
North Central Gyre	0.45 – 2.0	1.86	57
Balthic Sea	0.2 – 3.0	0.2 – 3.4	3 – 43
Oslofjorden (Norway)	0.45 – 5.0	0.1 – 30	15 – 90
Celtic Sea	0.2 – 2.0	0.7 – 12.4	20 – 30
Mediterranean Sea	0.2 – 3.0	2.5 – 9.2	25 - 90

After Stockner and Antia (1986)

Table 1. Productivity of Marine Algae and Picoplankton

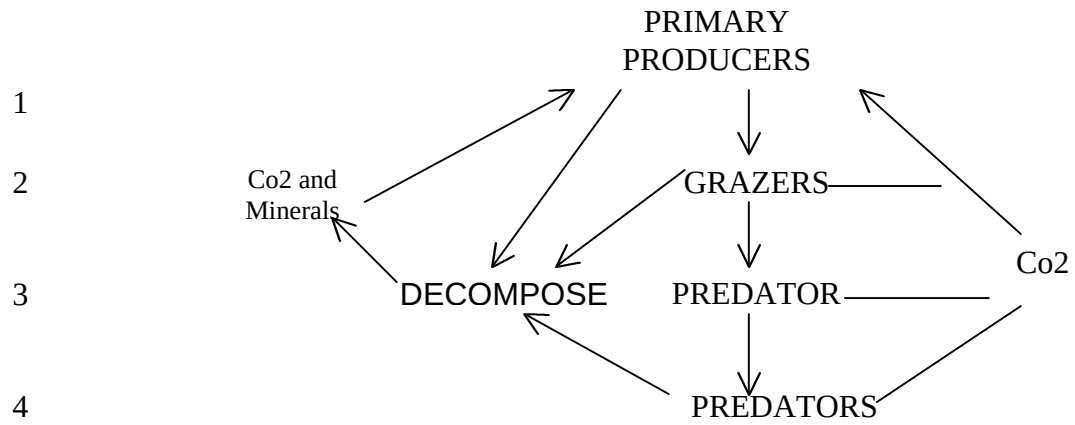


Figure 1. Carbon transfer through a food web (after Atlas and Bartha 1987)

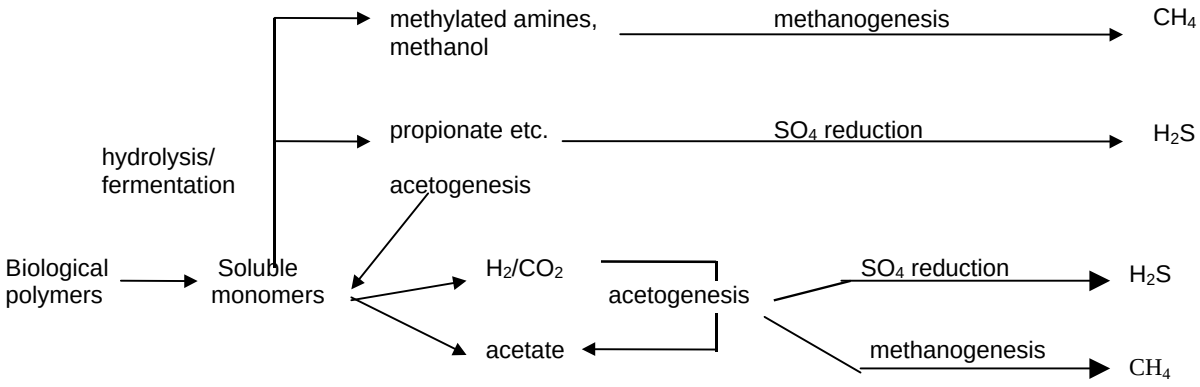
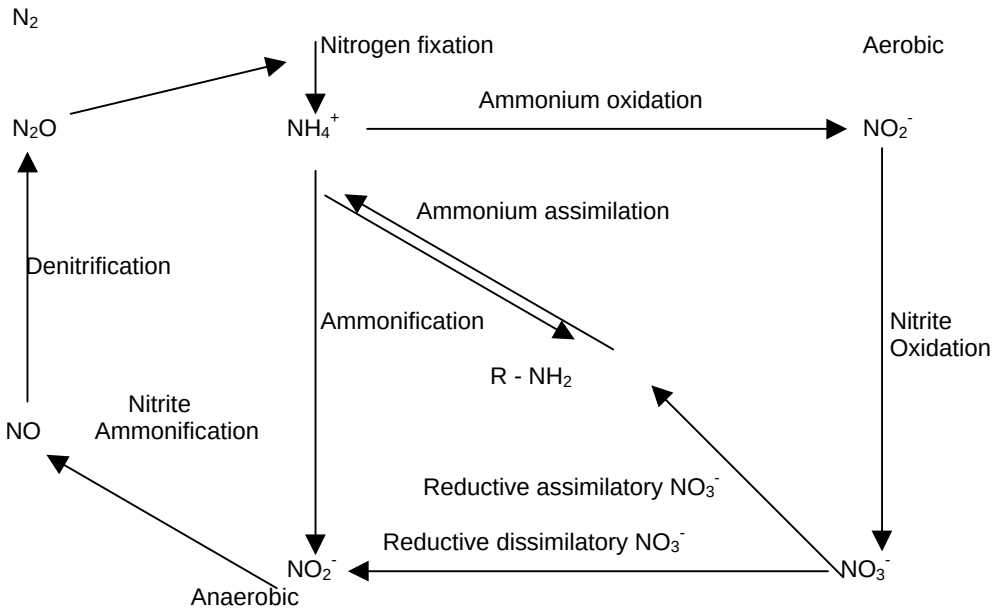


Figure 2. Carbon flow through an anaerobic marine sediment ecosystem (after Parkes, 1987)



FIigure 3. Natural Nitrogen Cycle (Source : Atlas and Bartha, 1993)