SIXTH FRAMEWORK PROGRAMME

Project contract no. 003933

THRESHOLDS
Thresholds of Environmental Sustainability
INTEGRATED PROJECT

Priority 1.1.6 "Sustainable Development, Global Change and Ecosystems"
Sub-Priority 1.1.6.3 "Global Change and Ecosystems"

Stream 3.4 – D3.4.1
Estimates of nutrient loading and sedimentation rates in selected coastal zones

Due date of delivery: May 2006
Actual submission date: April 2006

Start date of project: 1st of January 2005 Duration: 48 months

Lead authors for this deliverable: [Dr. Marianne Holmer (Syddansk Universitet)]

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
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Executive Summary

Assessment of nutrient loading and sedimentation in selected coastal zones through literature studies.

1. Introduction

Numerous studies show substantial and growing evidence that excess nutrients impact marine ecosystems (Borum 1996, Vitousek *et al*. 1997, Allen *et al*. 1998, Cloern 2001). Nutrient pollution introduced by humans, either directly or indirectly, of excess nitrogen and phosphorus results in deleterious effects to living resources or their habitats, impairment of water quality, and reduction in marine biodiversity (Cloern 2001). Marine and estuarine systems, bays, lagoons, open coastal waters seem especially affected by nutrient addition. Accelerated increase in the input of nutrients to the marine system represents a real threat to the integrity of marine ecosystems and the resource they support.

Nitrogen and phosphorus are essential elements for the growth of phytoplankton, macroalgae, and submerged aquatic vegetation. Marine plants form the base of marine food webs and provide essential habitat. Positive relationship between dissolved inorganic nitrogen flux and phytoplankton primary production are well-established and many data from many marine systems show a relationship between fisheries yield and primary production. There are thresholds, however, where the load of nutrients to a marine system exceeds the capacity for assimilation, and water quality degradation occurs with detrimental effects on components of the ecosystem and on ecosystem functioning. A continuum of nutrient input with an increase to a maximal point as nutrient load increases caused then a decline in various components of marine ecosystem as seasonal hypoxia (low dissolved oxygen) to permanent anoxia (no oxygen). Thus, increasing nutrients may be beneficial up to a point, but then habitat degradation and other more incipient damages occur.

Nutrients at natural levels in aquatic systems, or even excessive levels, are not usually toxic. However excess nutrients lead to increased phytoplankton or filamentous algal growth or the formation of harmful algal blooms (HABs). This phenomenon is called eutrophication. Increase in primary producers is not a bad thing, it implies more food for commercial fishes; however some HABs are toxic and can cause illness and death of fish, birds, marine mammals, and even humans (Smayda 1990). Secondary effects include increased sedimentation rate of organic matter and turbidity, providing increase in benthic macrofaunal biomass. The results cause higher benthic oxygen consumption that induces oxygen-depleted waters (Jørgensen 1980). The final symptom is a loss of habitat with consequences to alteration of marine biodiversity and changes in ecosystem structure and function. There are many examples of localized or temporary loss of biodiversity, shifts in community structure in both pelagic and benthic systems, and many examples of degraded habitats, such as coral reefs, seagrass beds, and commercial fisheries (Larsson *et al*. 1985). Species losses may be short-term or even permanent in localized areas (Wulf *et al*. 1990). Excess nutrients themselves do not kill, but their effects ultimately damage habitats. Over the last two decades it has become increasingly apparent that the effects of addition in excess of nutrients are not minor and localized, but have large-scale implications and are spreading rapidly (Rosenberg 1985).

The objective of many marine ecologists is to develop, evaluate and standardize easy and fast methods for determination of the thresholds of nutrients concentrations that might impact estuarine and coastal waters. There are many methods used by governmental agencies to determine nutrients content in seawaters but none of it is able to find the limit of nutrient concentration that could change some parameters in the environment. However the analysis of sediment cores from estuaries may provide useful insights into their environmental history and health. In many estuaries the rate and nature of sedimentation has significantly changed since the increase of the population and agriculture. In this report, we will try to get an overview of what has been done in the literature concerning study of sedimentation rate and possible relationship with nutrient loading, and different methods used to measure the impact of nutrient enrichment and sedimentation rates.

2. Assessment of nutrient loading

2.1. Sources of nutrients

2.1.1. Nitrogen

Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Inorganic nitrogen is found both as oxidized species (*e.g.* nitrate (NO_3^-) and nitrite (NO_2^-)) and reduced species (*e.g.* ammonia (NH_4^++NH_3) and dinitrogen gas (N_2)). In the seawater, ~95% of ammonia is in the cationic form which is called ammonium (NH_4^+). Total dissolved nitrogen (TDN) consists of dissolved inorganic nitrogen (DIN) and dissolved organic nitrogen (DON), and is readily available for plant uptake. DIN comprises NO_2^-+NO_3^++NH_4^+. Dissolved organic nitrogen is found in a wide range of complex chemical forms such as amino acids, proteins, urea and humic acids. Ammonium is the form of nitrogen taken up most readily by phytoplankton because nitrate must first be reduced to ammonia before it is assimilated into amino acids in organisms. The particulate nitrogen pool consists of plants and animals, and their remains, as well as ammonia adsorbed onto mineral particles. Particulate nitrogen can be found in suspension or in the sediment (included in sediment organic matter). Some portion of the particulate nitrogen pool is subject to rapid mineralisation, and is biologically available. Total nitrogen (abbreviated TN) is a measure of all forms of dissolved and particulate nitrogen present in a water sample.

2.1.2. Phosphorus

Phosphorus is another key nutrient in the marine's ecosystem. Phosphorus occurs in dissolved organic and inorganic forms, often attached to particles of sediment. This nutrient is a vital component to cellular growth and reproduction for organisms such as phytoplankton and bacteria. In the presence of oxygen, high concentrations of phosphates in the water will combine with suspended particles.

2.1.3. Nutrients and sediment organic matter

Organic matter in sediment consists of carbon and nutrients in the form of carbohydrates, proteins, fats and nucleic acids. Bacteria quickly eat the less resistant molecules, such as the nucleic acids and many of the proteins. Sediment organic matter is derived from plant and animal detritus, bacteria or plankton formed *in situ*, or derived from natural and anthropogenic sources in catchments. Sewage and effluent from food-processing plants, pulp and paper mills and fish-farms are examples of organic-rich wastes of human origin. Sediment nutrients are assessed as Total Nitrogen (TN) and Total Phosphorus (TP) concentrations, and have inorganic as well as organic sources. The amount of organic matter found in sediment is a function of the amount of various sources reaching the sediment surface and the rates at which different types of organic matter are degraded by microbial processes during burial.

2.1.4. Causes of sediment nutrients content changes

Excessive nutrients load cause eutrophication that is defined as an increase in the rate of organic matter in an ecosystem, and therefore of particulate organic matter supplied to bottom sediments. Dissolved nutrients are released from the sediment to the water column. Nutrients such as nitrogen and phosphorus are vital to the growth and survival of plants and production of animal tissue within marine waters, just as the nitrogen and phosphorus in fertilizer (Figure 2.1) aids the growth of agricultural crops.

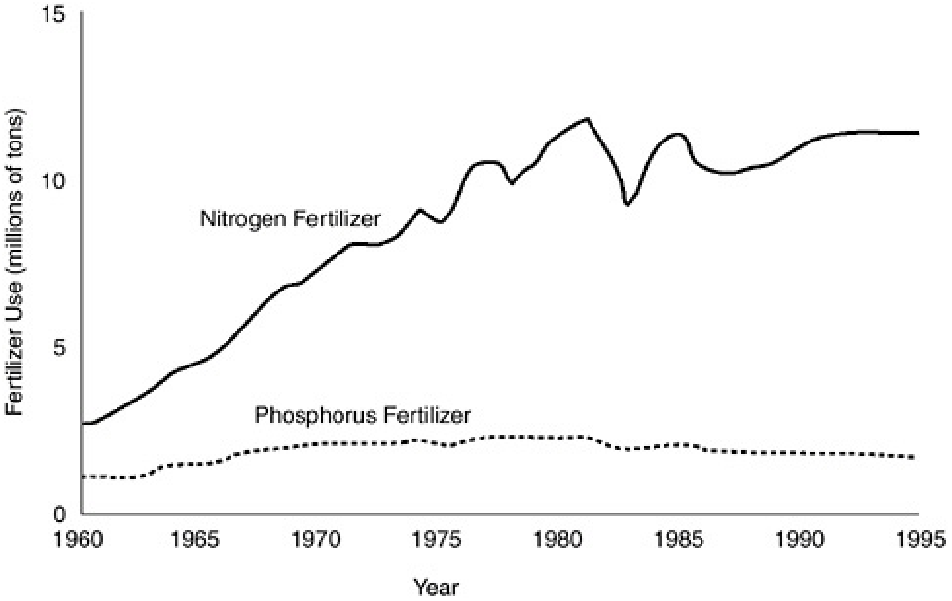

Figure 2.1. U.S. commercial fertilizer used from 1960 to 1995. Source: www.epa.com

Although nutrients are essential to all plant life, an excess of these same nutrients can be harmful. Nutrients have always existed in marine waters, but not at the present excessive concentrations. By the past with forest and wetlands, very little nitrogen and phosphorus ran off the land into the water. Most of it was absorbed or held in place by the natural vegetation. Today, farms, cities, and suburbs have replaced much of the forests and wetlands. As the use of the land has changed and the watershed's population has grown, the amount of nutrients entering the marine water has increased tremendously.

Excess amounts of phosphorus and nitrogen cause rapid growth of phytoplankton, creating dense populations, or blooms. These blooms become so dense that they reduce the amount of sunlight available to submerged aquatic vegetation (SAV). Without suffice light, plants cannot photosynthesize and produce the food they need to survive. The loss of sunlight can kill the seagrasses. Algae may also grow directly on the surface of SAV. Unconsumed algae will ultimately sink and be decomposed by bacteria in a process that depletes bottom waters of oxygen. Like humans, most aquatic species require oxygen. When oxygen in deep water is depleted, fish and other species will die unless they move to other areas of suitable habitat. These nutrients occur naturally in soil, animal waste, plant material, and even the atmosphere. In addition to these natural sources, sewage treatment plants, industries, vehicle exhaust, acid rain, and runoff from agricultural, residential and urban areas contribute nutrients to the Bays, estuaries, and lagoons (cf. Table 2.1).

Table 2.1. Sources of nutrients to the Baltic Sea; Total Inputs (tons/year). Source: Wulf *et al.* 1990

		Total P	Total N
Bothian Bay	Municipal	100	1,900
	Industrial	200	2,300
	Rivers	2,400	36,900
	Atmosphere	600	19,000
	N2 fixation	-	-
	Subtotal	3,300	60100
Bothnian Sea	Municipal	200	3,100
	Industrial	400	1,700
	Rivers	1,900	33,500
	Atmosphere	1,400	43,000
	N2 fixation	-	3,800
	Subtotal	3,900	85,100
Gulf of Finland	Municipal	600	8,500
	Industrial	200	1,100
	Rivers	4,200	65,900
	Subtotal	5,000	75,500
Baltic Proper	Municipal	11,700	53,500
	Industrial	600	5,700
	Rivers	38,200	447,400
	Atmosphere	3,800	252,300
	N2 fixation	-	130,000
	Subtotal	54,300	888,900
The Sound of Belt Sea	Municipal	5,500	20,100
	Industrial	2,200	3,200
	Rivers	3,400	56,800
	Subtotal	11,100	80,100
Baltic Sea	Total	77,700	1,189,700

Increase in sediment nutrients is associated with:

- decreased environmental flows and entrance modification (decreased flushing, increased residence times);
- diffuse nutrient sources including catchment landuse and run-off (rural and urban);
- eutrophication;
- nuisance growth of aquatic plants or algae (harmful algal blooms), and loss of amenity;
- point sources of pollution including industrial and aquaculture discharge (Table 2.2), sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater; and poor water quality from increased nutrients.

Table 2.2. Nutrients loading in Chesapeake Bay (2004). Source: www.Chesapeake.com

Pollution Source	N Load sources	P Load sources	Sediment Load Sources
% Agriculture	49	63	72
% Forest	21		17
% Point Source	11	18	
% Developed Land	7	7	5
% Mixed Open Land	7	8	6

2.2. Development of sensitive indicators of changes in nutrient content

2.2.1. Measurements of sensitive indicators

Total nitrogen (TN) and total phosphorus (TP) are determined by analyzing unfiltered water samples. Dissolved nutrients pass through a 0.45µm filter and are reported as: soluble reactive phosphorus (SRP) or filterable reactive phosphorus (FRP) in the case of phosphorus; and total dissolved nitrogen (TDN) in the case of nitrogen. TDN can be further analyzed for nitrate, nitrite, ammonium and organic nitrogen. The term 'reactive' implies that the nutrient readily reacts with the analytical chemical process (spectrophotometry or colorimetry).

2.2.2. Biological Indicators

Changes in the following biophysical parameters may indicate that a coastal waterway is receiving excessive nutrient loads:

- Turbidity Levels in excess (guidelines from agencies and governments, e.g. ozestuaries.com (Australia), epa.com (US));
- A lowering of denitrification efficiencies;
- A lowering of Total Organic Carbon (TOC)/Total Sulfur (TS) ratio;
- Concentrations of nutrients in macroalgal tissue over long time frames;
- Increase of the phytoplankton community structure/Chlorophyll-*a* is probably a better 'instantaneous' indicator;
- Reduction in seagrass areas/ Changes in the depth distribution of seagrasses;

- Reduction in the abundance and diversity of benthic invertebrate communities and fish assemblages;
- Sedimentation of organic material ^{14}C
- Increased sedimentation rates;
    - At each site, surface sediment samples should be collected and analyzed for the total amount of a nutrient and the amount in its dissolved form (measured by CHN analyzer), Phosphorus measured by wet chemical oxidation.
    - The rate of accumulation of nutrient in sediment (nutrient/cm^2/year) is probably more indicative of nutrients loads than sediment nutrient concentrations since the latter are subject to dilution effects caused by the co-deposition of mineral sediment (Figure 2.3.).

2.2.3. Routine measurements

Since nutrients are routine measurements (cf. Table 2.3.), large amounts of data exist for estuaries and coastal waterways from around the word. The data is held by the collecting agencies (state, local government, community groups and environmental consultants). Conceptual Models illustrating nitrogen transport pathways in tide-dominated deltas, tide-dominated estuaries, tidal creeks, wave-dominated deltas, wave-dominated estuaries, lagoons, are available in the governmental database. However, it would be advantageous to derive threshold values for these systems related with field experiments.

Table 2.3. Routine measurements used by governmental agencies

Eutrophication indicators	Methods	Detection Range
Field		
Water clarity	Secchi depth	0.1 m
pH	CTD probe/probe	0.01 pH
Dissolved oxygen	CTD probe/probe	0.02 mg DO/L
Salinity	salinometer	0.1 psu
Light attenuation	Light Sensor Li-Cor	0.05%
Temperature	CTD probe	0.1 degree C
Phytoplankton biomass	5-day method	
Zooplankton biomass	5-day method	
Chlorophyll *a*	Fluo, spectro, HPLC	
Phaeophytin	Spectro, HPLC	
Diatom density	Spectro, density	
Dinoflagellate density	Spectro, density	
Dinoflagellate/Diatom	Spectro, density	
Phytoplankton Blooms	Spectro, density	
Perennial plant density	density/SAV	
Ephemeral plant density	density	
Epiphytic growth	density	
benthic organisms diversity		
benthic organisms density		
Fish kills		

Laboratory analyses		
Total Phosphorus	Ascorbic acid method	0.3 μM
including orthophosphate	Auto-persulfate method	0.32 μM
POP, and DOP	Auto-persulfate method	0.02 μM
Dissolved orthophosphate	Ascorbic acid method	0.03 μM
Particulate phosphorus	Ascorbic acid method	0.04 μM
Total N	Persulfate method	0.36 μM
DIN, and PON	Persulfate method	0.7-143 μM
Total Kjeldahl N	Semi-micro Kjeldahl method	1.9 μM
ammonia/ammonium	Colorimetric method	0.7-1429 μM
Nitrate	Cadmium reduction	35.7-714 μM
Nitrite	Cadmium reduction	35.7-714 μM
Nitrate + Nitrite	colorimetric method Cadmium reduction Technicon autoanalyzer	0.01 μM 35.7-714 μM 0.7-143 μM
Particulate N	Filtration/combustion	1.36 μM
Total organic carbon	Wet oxidation Persulfate method	0.1 mg C/L 0.01 mg TOC/L
Dissolved organic carbon	Persulfate method Catalytic combustion	0.01 mg TOC/L 0.5 mg/L
Particulate Carbon	Filtration/combustion	0.097 mg/L
Total Silicates	Heteropoly blue method Molybdosilicate method	0.33-0.83 μM 0.22 μM
Total suspended solids	Dried at 103-105 degree C Filtration/Heat	2-20,000 mg/L 2 mg/L
Total volatile solids	Filtration/Heat	2 mg/L
BOD	5-day method	

COD	5-day method	

And it is also needed to establish the complex combination of nutrient loadings with hydrodynamics factors causing eutrophic conditions in estuarine and coastal waterways.

2.3. Sedimentation Rates

2.3.1 Definition

Sedimentation rate refers to the amount of material (organic and mineral) deposited by the action of water over a given interval of time. Sedimentation is measured in terms of vertical accumulation over time or sediment density per unit area over time:

(1) Vertical accumulation (mm y^{-1}) = Changes in the rate at which estuaries have been vertically filling up with sediment. Measurement of vertical accumulation of sediments can provide useful insights into the functioning and health of an estuary. Marked increases in modern rates of infilling may reflect increased catchment erosion and/or the increased production of organic sediment within the estuary, and indicate that abrupt changes have occurred in estuarine geomorphology and benthic habitats.

(2) Mass accumulation (g cm^2 y^{-1}) = Sediment mass accumulation is a more accurate measure of sedimentation where there are significant changes with depth in the density of estuarine sediment that may be related to compaction or changes in the composition of the sediment.

2.3.2. Variation of sedimentation rates

Sedimentation rate variations are caused by natural control on coastal waterways including climate (rainfall, seasonality), geology, slope (or topography), vegetation and the size of the catchments. Sedimentation rates can be used to determine the enhanced sediment loads due to changes in catchment land use practices. Increase of the sedimentation rates can give rise to:

- Rapid changes in the form and function of coastal waterways (sediment infills channels cause changes in hydrological functioning); leading to shallow estuary.
- Increase of the turbidity levels and sediment-bound nutrients (TN, TP, and TOC) and other toxicants (Figure 2.2.); the increase of turbidity limit the light penetration and photosynthesis. The increase of loads of particle-bound nutrients leads to eutrophication.
- Reduction in biodiversity, losses of seagrasses and macroalgae and constitute pressures on fishes and benthic invertebrate numbers; more organic matter is degraded by anoxic processes (*e.g.* sulfate reduction; see also TOC:TS ratios).
- Denitrification efficiencies are lowered under anoxic conditions. Losses of denitrification are an important cause of oxygen reduction.
- More dissolved nutrients are recycled to the water column.

In order to make better-informed management decisions there is a clear need to accurately assess the rate and nature of sedimentation within coastal waterways and any changes in other sedimentological parameters over time.

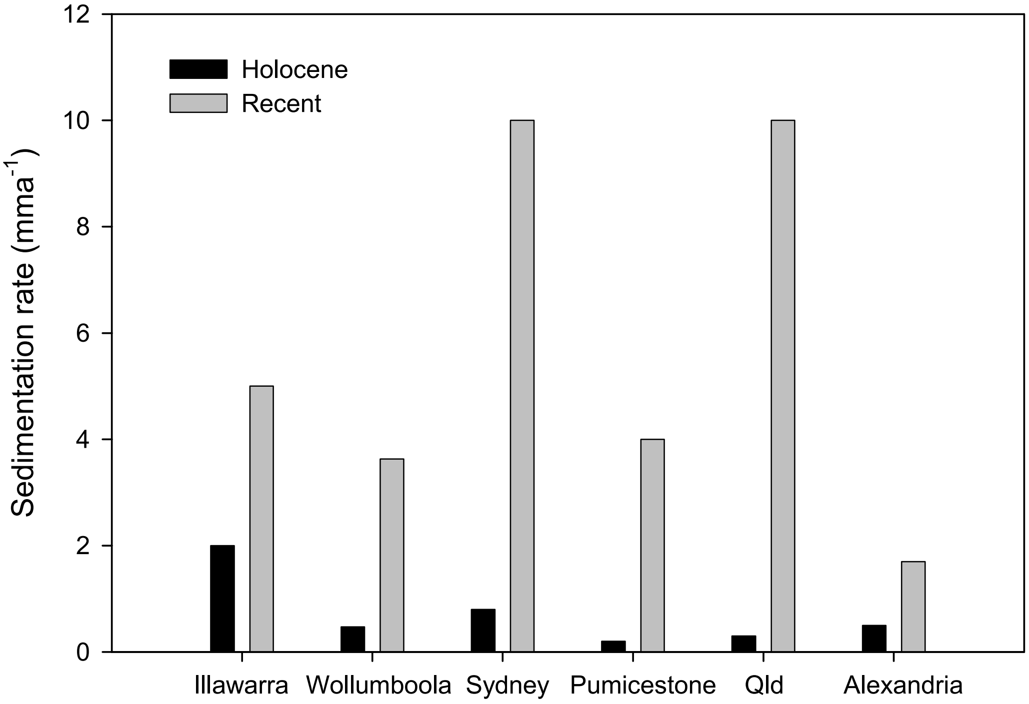

Figure 2.2. Difference between sedimentation rates in Holocene and recent in Australian deltas and Sydney harbor. The units are in mm a^{-1} = sediment accumulation per area per time in km^{-2} y^{-1}. Source: 2002-ozestuaries.com's database.

2.3.3. Other sedimentological indicators

Other geochemical analyses of sediment cores can identify pools of nutrients or other pollutants within the estuary fill. This is important information for managers because of the potential for the release of sediment-bound nutrients into the water column, which is also relevant where dredging work is proposed. The identification of microfossils in sediment cores can provide a detailed record of recent changes in estuarine vegetation communities or harmful algal blooms. These data can aid the development of models of sediment transportation.

2.3.4. Measurement and interpretation

Sedimentation rates are assessed by sediment trap for a short time period. However, sedimentation rates measured during a short time period might show considerable variability both in time and space (Christiansen *et al*. 2002). Dating sediment cores taken from coastal waterways can be more accurate.

2.3.4.1. Dating Methods

It is possible to identify changes in sedimentation rates, as well as the timing of key historical events, in estuary and coastal waterways through measurement of radio-active isotopes.

- Lead 210 - this technique is the one method capable of providing high-resolution ages for sediments over the last 150 to 200 years. It works best on mineral and organic-rich sediment. Lead-210, which is part of the uranium-238 (^{238}U) decay series, is absorbed onto sediment particles deposited in lakes and estuaries. It consists of both supported and unsupported components. The former refers to that component which is in equilibrium with all members of the decay chain, which precede it. It is derived from the *in situ* decay of radium-226 (226Ra) that has been directly washed into the system as part of eroded material. Unsupported ^{210}Pb is derived from radon-222 (^{222}Rn), which diffuses as gas through the soil interstitial pore space into the atmosphere, where it rapidly decays to ^{210}Pb. The ^{210}Pb then attaches to aerosol particles and settles out of the atmosphere as dry fallout or is washed out in rainfall events. This 'unsupported' ^{210}Pb can fall directly onto the sediments or be washed in at a later time from elsewhere in the catchment. In either event, once deposited and incorporated in the sediment, the activity of unsupported ^{210}Pb will be solely a function of the amount present initially and its half-life (half-life = 22.6 year). Thus, a ^{210}Pb-chronology can be determined for a sediment core by measuring the down-core activities of unsupported ^{210}Pb and comparing these with that measured for the modern sediments at the top of the core. The activity of supported ^{210}Pb can be determined indirectly by measuring the activity of ^{226}Ra (see below) using either alpha or gamma spectrometry. Unsupported ^{210}Pb cannot be measured directly and so is inferred from the activity of total ^{210}Pb minus the activity of supported ^{210}Pb. The activity of total ^{210}Pb can be determined by either measuring ^{210}Pb directly using gamma spectrometry or measuring (using alpha spectrometry) the progeny ^{210}Po with which it is assumed to be in secular equilibrium.

- $^{206/207}$Pb (Dellwig *et al*. 2000)
- ^{239,240}Pu, and ^{240}Pu/^{239}Pu ratio
- ^{226}Ra (San Miguel *et al*. 2003, Vaalgamaa 2004)

- ^{241}Am (Plater & Appleby, 2004)

- ^{60}C (half-life 5 years) Croudace & Cundy 1995

- Radiocarbon (^{14}C), optically stimulated luminescence (OSL) and thermoluminescence (TL) - methods useful for dating sediments of prehistoric age. ^{14}C is most useful on organic marine sediment older than ~600 years (due to the marine reservoir effect) and younger than 40,000 yrs. OSL and TL are applied to the mineral component of sediment (quartz, feldspar) and have a greater age range than ^{14}C. The OSL method can also be used to date sediment deposited during the past few decades.

- Isotope Bi-207

- aspartic acid racemisation - this technique may be applied to sediments deposited <600 years ago. This method is also referred to as Amino Acid Racemisation (AAR) dating;

- Approximate (proxy) dates determined from distinct layers in the sediment horizon related to known events within the catchment. These include major erosion events such as floods, the onset and cessation of mining or pesticide use, the first appearance of radioactive fallout (mainly ^{137}Cs) from atmospheric nuclear weapons tests, and the first occurrence of exotic pollen. In addition to providing their own chronology, these horizons are used to validate the above dating methods.

2.3.4.2. Potential Complications

- Reworking of superficial sediments (*i.e.* the top few centimeters by currents and burrowing animals);

- Bioturbation and bioirrigation of sediment;

- Advective transport of sediment in tunnels of burrowing animals.

- Diffusion of soluble sediment;

- Contamination of sediment by radiocarbon older than the sediment;

- Incomplete bleaching of the quartz and feldspar (leads to an overestimate of the luminescence age).

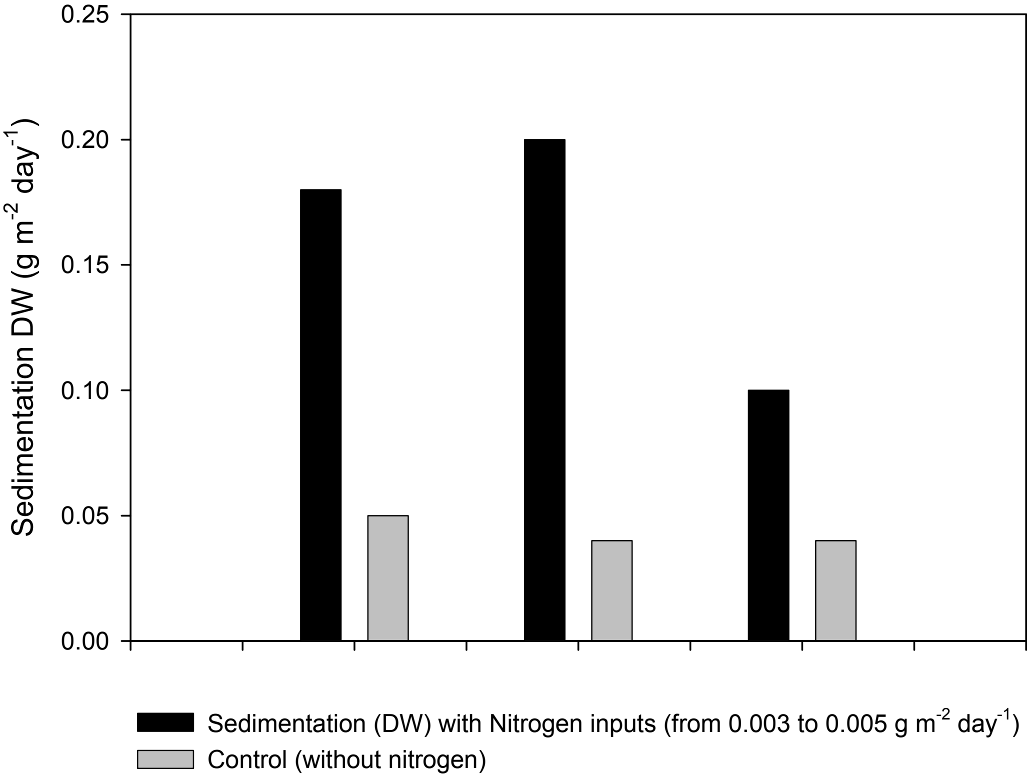

Figure 2.3. Increased of sedimentation rates (DW=dry weight) related to input of nitrogen from 0.003 to 0.005 $gm^{-2}day^{-1}$. Units are in $gm^{-2}day^{-1}$. Source: Andersson *et al.* 1998

3. SOME RESULTS

Table 3.1. Examples of sedimentation rates in the literature

Infill Rate mm/a^{-1}			Dating Method	Reference
Estuary	**Holocene**	**Recent**		
Bega River		3.1-3.4 mm a^{-1}	^{210}Pb	Hancock 2000
Moreton Bay		6,12 mm a^{-1}	^{210}Pb, ^{137}Cs	Hancock 2001
Pumicestone Passage	0.2 mm a^{-1} 0.3 mm a^{-1}	4 mm a^{-1} 10 mm a^{-1}	^{14}C, ^{210}Pb pollen	Brooke 2002
Stokes Inlet		17;20 mm a^{-1}	^{137}Cs	Hodgkin & Clark 1989
Torbay Inlet		9.2 mm a^{-1}	^{210}Pb	Geoscience
Walepole Inlet		4.6 mm a^{-1}	^{210}Pb	Geoscience
Chesapeake Bay		0.09,0.12 cmy^{-1}	^{210}Pb	Schubel & Hirschberg 1977
Winyah Bay		5.5 mm y^{-1}	^{210}Pb	Patchineelam 2000
Tivoli South Bay		0.59 to 2.92 cm y^{-1}	^{210}Pb, ^{137}Cs	Benoit *et al*. 1999
Tagus Sado		0.16 to 2.13 cm y^{-1}	^{210}Pb	Jouanneau *et al*. 1998
Lower Hudson river estuary	1-3 mm y^{-1}	1-3 mm y^{-1}	137 Cs, ^{14}C	Klingbeil & Sommerfield 2005
Ho Bugt		4 mm y^{-1}	^{210}Pb, ^{137}Cs	Madsen *et al*. 2005
Palmones River		0.7 cm y^{-1}	^{210}Pb, ^{137}Cs	Rubio *et al*. 2003
Gulf of Mannar		17.37 mm y^{-1}	^{210}Pb, ^{137}Cs	Ramesh *et al*. 2002
Bay of Biscay		0.2 cm y^{-1}	^{210}Pb	Lesueur *et al*. 2001
Chesapeake Bay	0.5 to 0.7 cm yr-1	1 gcm^{-2} y^{-1}	^{210}Pb	Pasternack & Brush 2001 Arnold *et al*. 2000
Scheldt esturay		280 Mkg y^{-1}		Baeyens *et al*. 1998
Ria de Gernika		0.73 to 1.29 cm y^{-1}	^{210}Pb, ^{14}C	Pascual *et al*. 1998

Fraser Delta		3 cm y^{-1}	^{137}Cs	Hart *et al*. 1998
Thau Basin		0.09 to 0.18 gcm^{-2}y^{-1}	^{210}Pb	Monna *et al*. 1997
Rhone estuary		35 cm y^{-1}	^{14}C, ^{137}Cs	Calmet & Fernandez 1990
Portil lagoon		0.08 to 0.17 gcm^{-2} a^{-1}	^{210}Pb, ^{137}Cs	Miguel *et al*. 2003
Salton Sea		2.3 mm y^{-1}	^{210}Pb	Schroeder *et al*. 2002
Ria de Vigo	1.12 mm a^{-1}	3.3-4.4 mm a^{-1}	^{14}C	Perez-Arlucea *et al*. 2005
Southern Okinawa trough		0.14-1.68 cm y^{-1}	^{210}Pb, ^{137}Cs ^{239},^{240}Pu	Lee *et al*. 2004
Salton Sea		2.3 mm y^{-1}	DBD	Schroeder *et al*. 2002
Chesapeake Bay		0.46 gcm^{-2}y^{-1}	^{210}Pb	Officer *et al*. 1984
Laajalahti Bay	1900 2000	0.03 gcm^{-2}y^{-1} 0.13 gcm^{-2}y^{-1}	^{210}Pb, ^{137}Cs ^{226}Ra	Vaalgamaa 2004
Skagerrak		843 gm^{-2} y^{-1}	^{210}Pb	Kunzendorf *et al*. 1998
Skagerrak		278 gm^{-2} y^{-1}	^{210}Pb	Kunzendorf *et al*. 1998
Skagerrak		356 gm^{-2} s^{-1}	^{210}Pb	Kunzendorf *et al*. 1998
Northern Belt Sea		625 gm^{-2} y^{-1}	^{210}Pb	Christiansen *et al*. 1997
Kattegat		4.3 mm y^{-1}	^{210}Pb	Christiansen *et al*. 1993
Central Kattegat		3.3 mm y^{-1}	^{210}Pb	Christiansen et al. 1993
Kattegat		469-757 gm^{-2} y^{-1}	^{210}Pb	Christiansen *et al*. 1997
Pine Log Creek		1.4 mm y^{-1}	^{210}Pb	Trimble *et al*. 1999
Florida's Gulf of Mexico		1.4 mm y^{-1}	^{210}Pb	Hoenstine *et al*. 1993
Gotland Basin, Baltic Sea	east 0.75 mm a^{-1} central 0.33 mm a^{-1} western 0.23 mm a^{-1}	2.1 to 2.5 mm a^{-1}	^{210}Pb	Christiansen *et al*. 2002

Gulf of Gdansk		100 mg DW $m^{-2}h^{-1}$	sediment traps	Witek *et al*. 1999
Hudson River estuary	1 to 3 mm y^{-1}	10 cm y^{-1}	^{137}Cs ^{14}C	Klingbeil & Sommerfield 2005 Olsen *et al*. 1978
Tees estuary		0.761 g cm^{-2} y^{-1} (1950) 11 g cm^{-2} y^{-1} (2004)	^{210}Pb ^{137}Cs	Plater & Appleby 2004
German Wadden Sea	1.207 mm y^{-1}	1.172 mm y^{-1}	$^{206}Pb/^{207}Pb$	Dellwig *et al*. 2000
Toolonlahti, Finland		0.4 to 0.6 cm y^{-1}	^{137}Cs, ^{14}C	Virkanen 1998
Danish Wadden Sea		8 mm a^{-1}	^{210}Pb, ^{137}Cs	Andersen & Pejrup 2001
Toolonlahti, Finland	0.6 cm y^{-1}	55 cm y^{-1}	^{210}Pb	Tikkanen *et al*. 1997
Skagerrak	cf graphs		sediment trap	Noji *et al*. 2002
Portil lagoon	0.08 cm a^{-1}	0.17 cm a^{-1}	^{210}Pb, ^{137}Cs	San Miguel *et al*. 2003
Winyah Bay		5.5 mm y^{-1}	^{210}Pb	Patchineelam *et al*. 1999
Ria de Gernika	0.01 cmy^{-1}	1.29 cm y^{-1}	^{210}Pb ^{14}C	Pascual *et al*. 1998
Guanabara Bay		2.65 g cm^{-3}	^{210}Pb	Godoy *et al*. 1998

Table 3 shows some studies measuring sedimentation rates. It might be possible to relate nutrients and sedimentation rates if studies measuring sedimentation rates and nutrients were done in the same time and if authors were using same units. Moreover following these results, sedimentation rates show considerable variability both in time and space (Christiansen *et al*. 2002).

A few studies show relations between sedimentation rates and nutrients loading, and some examples are given below.

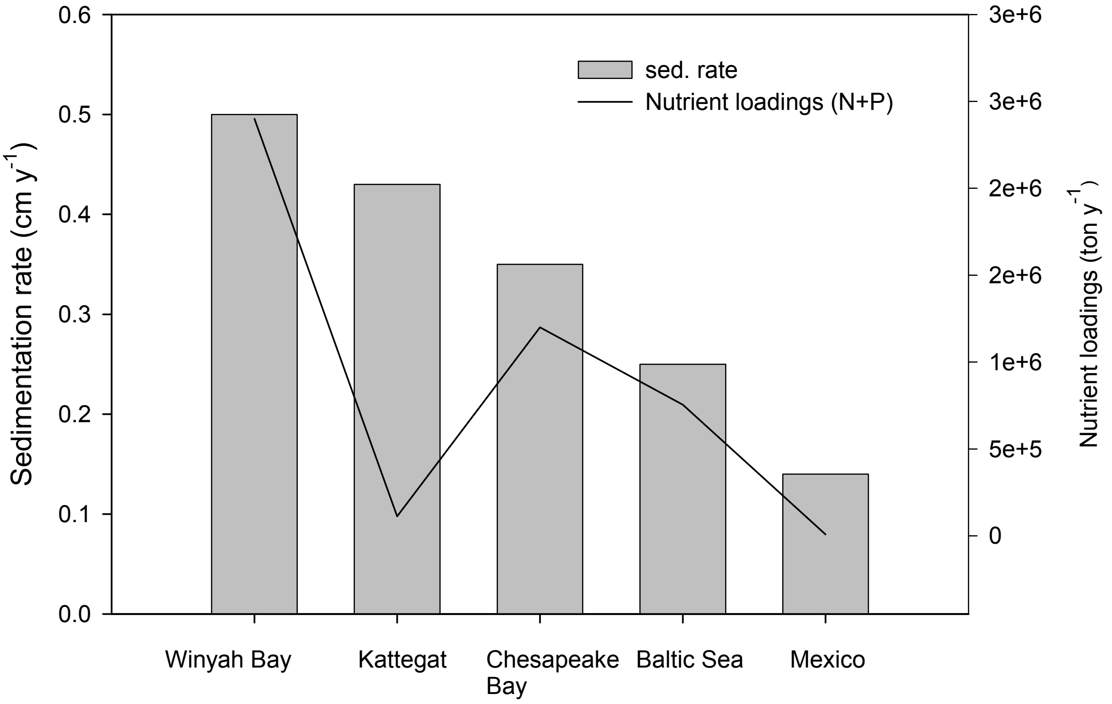

Figure 3.1. Sedimentation rates vs nutrients loading from different sites. Source: Table 3.1

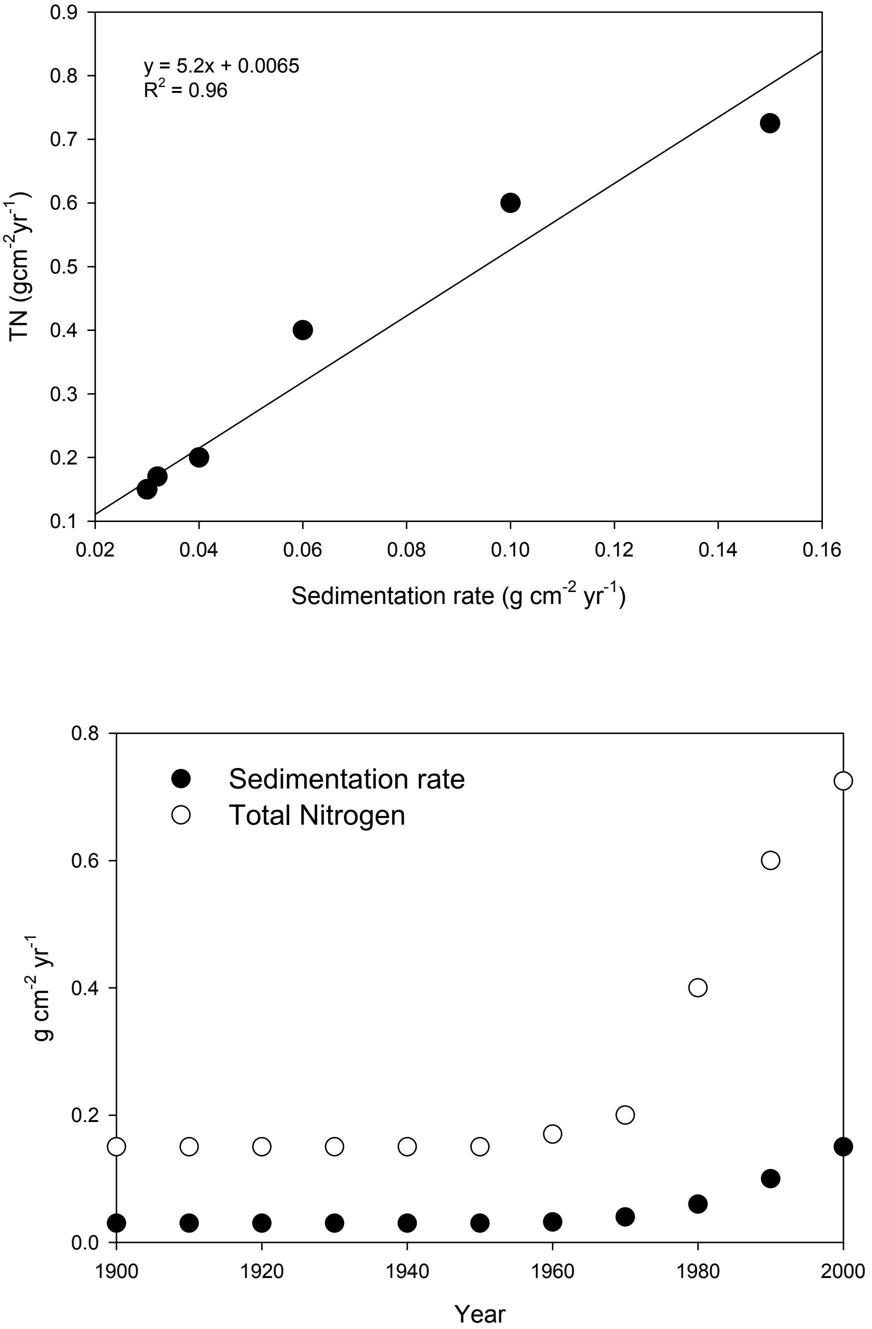

Figure 3.2. Correlation between sedimentation rates and nutrients loading. Laajalahti Bay, Helsinki city. Units of sedimentation rate and TN are in $gcm^{-2}yr^{-1}$. Source: Vaalgamaa (2001)

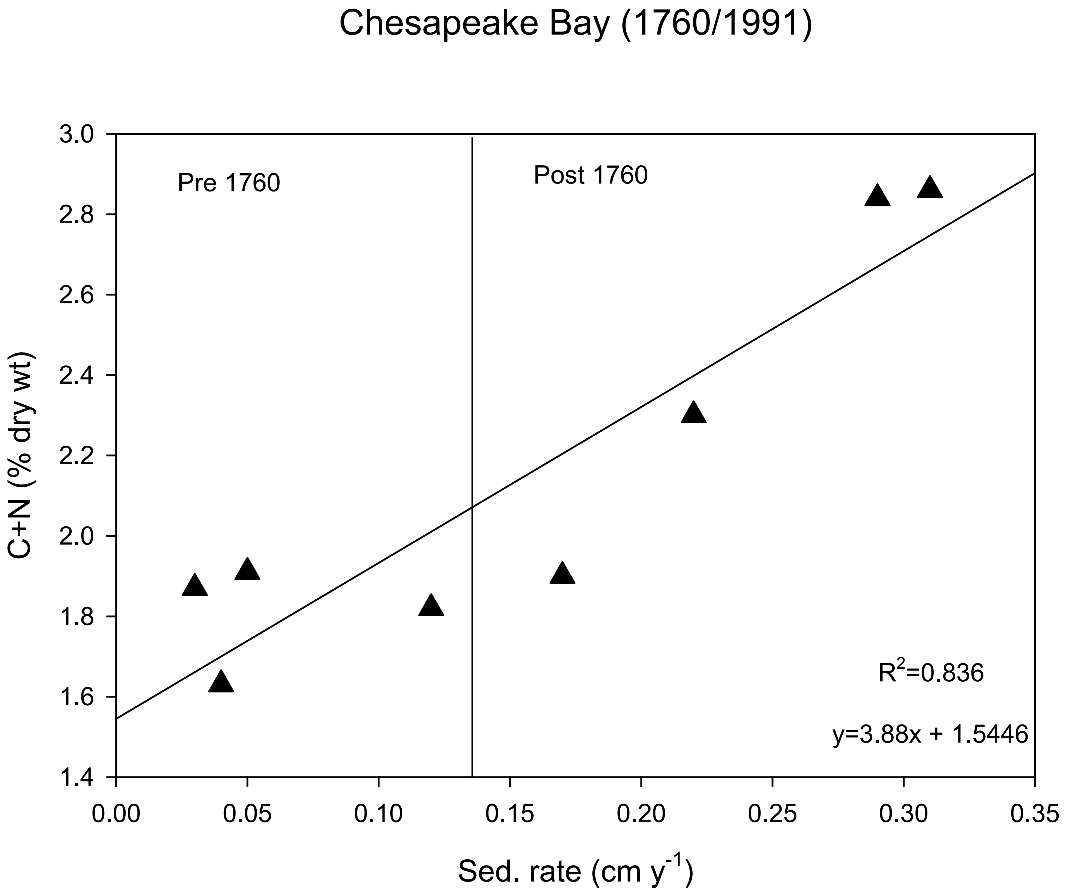

Figure 3.4. Correlation between sedimentation rate (Sed. rate in cm y^{-1}) and nutrients in the sediments (% dry wt) in Chesapeake Bay. Source: Cooper & Brush, 1991

Conclusion

Nutrient over-enrichment has resulted in major changes in the coastal ecosystems of developed nations in Europe, North America, Asia, and Oceania, over the period of 1960 to 1980. Many coastal areas are affected. Primary production has increased, water clarity decreased, food chains were altered, oxygen depletion of bottom waters developed or expanded, seagrass beds have disappeared, and harmful algal blooms occurred with increased frequency. This period of dramatic alteration of coastal ecosystems coincided with an increase in use of manufactured fertilizers during that 20-year period. Research has documented the consequences and origins of nutrient over-enrichment and has provided the basis for national statutes and regulations to multi-jurisdictional compacts under the Helsinki Commission for the Baltic Sea, the Oslo-Paris Commission for the North Sea, and the Chesapeake Bay Program, for example. These studies have seen reduction of inputs of phosphorus and nitrogen, principally through treatment of point-source discharges; however relatively little progress has been made in reducing diffuse sources of nitrogen. Second-generation management goals tend to find thresholds of the load nutrients to diagnose the degree of eutrophication, and contribute to desirable and achievable outcomes for rehabilitation efforts, reducing nutrient sources, enhancing nutrient sinks. The goal trying to correlate sedimentation rates and nutrient loading might be useful. Results showed that there are good correlations between sedimentation rates and nutrients loading. We might be able to find some thresholds based on these correlations but a lot of work has to be done. Research studies have to agree on the units, measurements of both sedimentation rates and nutrients have to be done in the same time and same site. Relations have to be determined carefully with environmental conditions, and access of all databases (e.g. governmental agencies) should help us to create a model that will be able to predict threshold in future.

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