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## Environmental records of anthropogenic impacts on coastal ecosystems: An introduction

### 1. Introduction

We proposed (and then chaired) in the Ocean Sciences 2008 meeting (2–7 March 2008, Orlando, Florida, USA) a Special Session on “Environmental Records of Anthropogenic Impacts on Coastal Ecosystems”. We were expecting a range of contributions from watersheds to oceans and we received them!

Increased awareness of environmental values has led policy-makers worldwide to develop and implement national and international legislation aimed to protect ecosystems. However, in most cases it is unknown or uncertain whether the implemented actions have had positive impacts on the environment. In most developing countries anthropogenic impacts are likely to be increasing. Coastal zones, the natural interface between watersheds and the oceans, are especially valuable ecosystems and are usually under intense anthropogenic pressure. Many pollutants accumulate in these sensitive ecosystems. We adopted a wide definition of pollutants, including all substances present in the environment that result from human activity, including metals, organic pollutants, nutrients, anthropogenic radionuclides, sediments and others. In fact, the reader will observe that even Climate Change, due to the input of greenhouse gases to the atmosphere, finds its place in this Special Issue. Some authors presenting to this and related sessions were invited to submit their work to this Special Issue.

### 2. Contents

Many scientific studies have used dated records to study a variety of phenomena, including anthropogenic impact and pollution. But, have they been used to their fullest potential? If a pollution record extends for the last 100 years, has this message reached the relevant decision-makers? Although a Special Issue of a science journal is not the best way to communicate with decision-makers, it is a good opportunity to put together information and ideas that may influence science policy in a positive direction.

#### 2.1. Relevance for decision-makers

It is not a coincidence that the first paper of this volume (Stein and Cadien, 2009) addresses two relevant issues. First, it is focused on an important management problem: we are trying to improve, but is it working? In their own words: “...monitoring programs should be designed to answer key management questions that will inform future decisions”. In our opinion this is one of the most important messages that can be conveyed to readers: a good record (either from monitoring or from environmental archives) describes

the recent past and present trends. Second, if society has invested resources to improve environmental conditions, how is success assessed? In this volume there are some examples, from different parts of the world, using various approaches and environmental matrices and indicators, of how success or failure is assessed. We hope that scientists are motivated to communicate the information they retrieve from environmental records to their coastal zone managers and other decision-makers.

#### 2.2. Monitoring versus environmental records

After reading Stein and Cadien, some readers might reach another conclusion: environmental monitoring is the best approach to assess changes. However, most often, results from monitoring programmes are not long enough to produce valid assessments, and they do not exist for most locations in the world. Stein and Cadien state: “A rare opportunity exists in southern California to evaluate the effectiveness of management actions by analyzing long-term monitoring...”. We could not agree more: if data are available, this is the best option, but usually it is not the case. Van der Meij and co-workers (2009) found a way around the scarcity of monitoring data; they compared molluscan fauna from the same area (Jakarta Bay, Indonesia) for two periods: 1937–38 and 2005. Though there are only two points, the results of the exercise are useful. But similarly, they state: “Long-term faunal comparisons (decades) in a single marine area are scarce...”. Is there another option? Yes, and most authors of this Special Issue address the problem by establishing environmental records.

#### 2.3. Environmental records: sediments

Sediments integrate pollution signals and, under certain conditions, can provide a reliable record of pollution levels, an indicator of ecosystem health. But for this to be possible, an accurate chronology is essential. From a generic point of view, several chronometers could be used (such as volcanic ashes or large floods) but absolute chronologies are commonly obtained from radionuclides. Radiocarbon is used to study impacts extending back at least a few centuries, but the most suitable tracer for these type of studies is  $^{210}\text{Pb}$  because its half-life ( $T_{1/2} = 22.20 \pm 0.22$  years) allows suitable dating for the last 100 years, when most of the anthropogenic impact has occurred.

There are several research papers addressing this timescale in this volume from many different regions of the world (Fig. 1). Though not complete, it might motivate scientists to consider similar studies in their countries. For example, the International Atomic Energy Agency (IAEA), through its Department of Technical

Cooperation, collaborates with Member States to promote the peaceful use of nuclear techniques. The main objective of one of its regional projects (RLA/7/012 “Use of Nuclear Techniques to Address the Management Problems of Coastal Zones in the Caribbean Region”) is to assist twelve Member States of the Wider Caribbean region to obtain 100 year records of anthropogenic impact by collecting, analyzing and interpreting sediment cores. It is expected that this scheme could be extended to other world regions and results could be delivered to the pertinent authorities.

In this issue, a number of environments and pollutants are studied (Table 1). It is not our objective to review in-depth all of these papers, but to highlight some interesting issues. Let us first indicate that the definition of “marine pollution” given by the United Nations Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) is “Introduction by man of substances into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities” (GESAMP, 1969). In their report “Protecting the Oceans from Land-based Activities” (GESAMP, 2001) they listed the following sources of impact: physical alteration, sewage, nutrients, sediment mobilization, POPs (Persistent Organic Pollutants), hydrocarbons (oil), heavy metals, litter and radionuclides.

#### 2.4. Sediment mobilization

It is interesting to note that some papers deal with the issue of sediment mobilization. This is not a coincidence, as sediment accumulation rates are one of the most useful parameters obtained when using  $^{210}\text{Pb}$  dating models of sediments. And yes, sediment mobilization (loss or accumulation) can be a very important anthropogenic impact, indeed! For example, the discussion provided by Gomes and co-workers (2009) showing that in Sepetiba Bay (Brazil) the construction of an impoundment caused increased river flow, doubling the sediment accumulation rates. One can imagine that the coastal landscape will be seriously affected by this in the long-term. Ruiz-Fernández and Hillaire-Marcel (2009) also

discuss how, for example, in Tehuantepec (Mexico) increased sediment accumulation rates are related to land use changes, such as deforestation for agricultural development and industrialization. Mulsow et al. (2009) report changes in sediment accumulation rates at Pillan and Reñihue Fjords due to aquaculture. From another perspective, Sta. Maria and co-workers (2009) estimate sediment accumulation rates in a complex sedimentary environment, Manila Bay (Philippines), with a relatively high degree of mixing, concluding that the observed change in accumulation rates observed in most cores is probably due to the Pinatubo eruption in 1991, thus providing a useful chronomarker in this environment. This is not an anthropogenic cause but it will be an important tool to interpret further research in this pollution hot-spot. Canuel and co-workers (2009) also look at sediment accumulation rates, but using as chronomarkers a variety of anthropogenic tracers including  $^{137}\text{Cs}$ , DDE and BDE, concluding that changes in sediment and carbon accumulation were due to the completion of several large reservoirs, and increased agriculture and urbanization in the Sacramento-San Joaquin River Delta watershed.

Regarding sediment accumulation rates and mixing, Mulsow et al., as well as Ruiz-Fernández and Hillaire-Marcel, make the point that no matter how “ugly” the  $^{210}\text{Pb}$  profiles appear in complex sedimentary environments,  $^{210}\text{Pb}$  is a tracer of environmental processes and, with additional information/experimentation and solid interpretative tools, may reveal useful information.

#### 2.5. Trace metals

There is a rapid development of techniques that allow scientists to determine a wider variety of pollutants with better sensitivities. Dolor and co-workers (2009) report a long list of “exotic” elements, rarely determined in pollution reconstruction studies, using laser ablation – ICPMS, and show for many of them an anthropogenic impact. Not only sensitivity is high, but the amount of information retrieved demands further research on the sources and geochemistry of these elements. Perhaps it will be possible to analyze sediment, with this sensitivity, by scanning cores in a continuous mode!

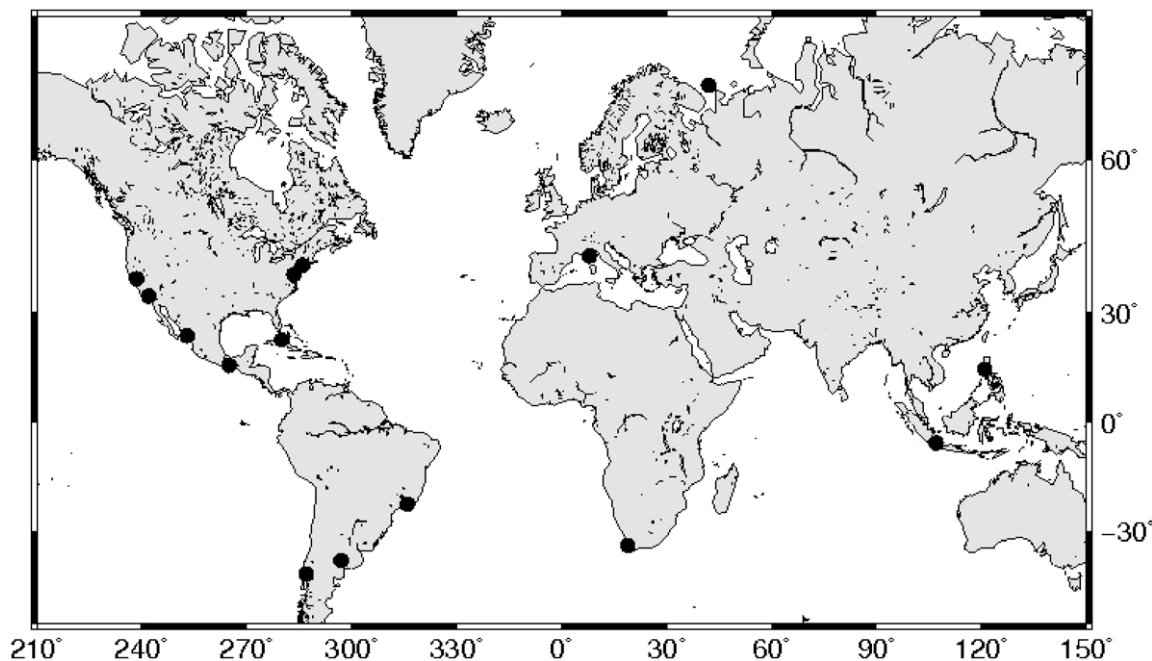


Fig. 1. Location of study sites reported in this issue.

**Table 1**

Synthesis of work reported in this volume.

First author (this volume)	Country studied	Region	Environmental matrix	Substances of interest
Canuel	USA	N Pacific Ocean	Sediment	$^{14}\text{C}$ , $^{137}\text{Cs}$ , total DDE, BDE, TOC
Carroll	Russia	Barents Sea	Shell (bivalves)	$\delta^{18}\text{O}$ , $\delta^{13}\text{C}$ , Mg, Sr, Ba, Mn, Ca
Díaz-Asencio	Cuba	Caribbean Sea	Sediment	$^{137}\text{Cs}$ , $^{210}\text{Pb}$ , Pb, Hg
Dolor	USA	N Atlantic Ocean	Sediment	S, Ca, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Nb, Mo, Ag, Cd, In, Sn, Sb, Te, W, Re, Tl, Pb, Bi, U ( $^{210}\text{Pb}$ )
Gomes	Brazil	S Atlantic Ocean	Sediment	$^{137}\text{Cs}$ , $^{210}\text{Pb}$ , Na, Mg, Al, K, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Nb, Mo, Cd, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, W, Pb, Bi, Th, U
Kading	South Africa	S Atlantic Ocean	Sediment	$^{210}\text{Pb}$ , Hg, methyl-Hg, TC
Martín	Italy	Mediterranean Sea	Sediment	$^{210}\text{Pb}$ , Zn, Pb, Cu, Cr
Mulsow	Chile	S Pacific Ocean	Sediment	$^{210}\text{Pb}$ , Fe, Mn, Al, dissolved O, TOC, image, magnetic susceptibility
Ruiz-Fernández	Mexico	N Pacific Ocean	Sediment	$^{210}\text{Pb}$ , $^{137}\text{Cs}$ , $\delta^{13}\text{C}$ , $\delta^{15}\text{N}$ , Al, Fe, Cu, Hg
Sta. Maria	Philippines	S China Sea	Sediment	$^{210}\text{Pb}$ , Si, Al
Stein	USA	N Pacific Ocean	Water, sediment and fish monitoring	BOD, TSS, oil and grease, organic N, total P, cyanide, DDTs, Cd, Cu
van der Meij	Indonesia	S China Sea	Mollusc monitoring	Fish and mollusc species
Wilson	USA	N Atlantic Ocean	Water and sediments	Triclosan, TSM
Ziolkowski	Laboratory experiments	Laboratory experiments	Sediment	Identity and characterization of BPCAs, % black carbon

Díaz-Asencio and co-workers (2009) show an extremely interesting case of mercury pollution from a chlor-alkali industry. The  $^{210}\text{Pb}$  profile is very well-defined and mercury levels are very high. Most importantly, this is an excellent example of how sediments record past activities and show how management decisions have significantly reduced pollution; and for this, decision-makers should be happy. Mercury is also the focus of study for Kading and co-workers (2009) who report, possibly for the first time in this region, a toxic metal record in a wetland sediment core from South Africa. Although levels are two orders of magnitude less than those found in Cuba (Díaz-Asencio et al., 2009), we cannot over-emphasize the importance of this type of work in regions where data are scarce. We encourage scientists to use these approaches to increase knowledge of the pollution trends in their coastal environments. A similar study is published by Gomes and co-workers (2009): they report large impact of Cd and Zn in Sepetiba Bay (Brazil) from a zinc metallurgical plant.

But not all articles address local pollution sources. Martín and co-workers (2009) show how a sediment core collected at 2300 m depth from the Mediterranean Sea reflects the regional atmospheric inputs of Pb, Zn and Cu. This is an important result related to the Dyfamed site, a long-term oceanographic monitoring station in the NW Mediterranean and demonstrates the importance of atmospheric transport and deposition of pollutants in the open sea environment.

### 2.6. Environmental records: shells

Although most of the contributions address pollution records in sediments, there are other possible matrices. Carroll and co-workers (2009) use shells to detect both anthropogenic impact and climate change. GESAMP (2001) not only defined “pollutants” but also identified climate change as an emerging issue related to pollution. In our opinion, not only does climate change have an anthropogenic origin, but its impacts can already be found in our ecosystems. As Carroll and co-workers state, “sclerochronological proxies can be useful retrospective analytical tools for establishing a baseline of ecosystem variability in assessing potential combined impacts of climatic change and increasing commercial activities on Arctic communities”.

### 2.7. Other anthropogenic impact indicators

There are two method-oriented contributions in this issue. Ziolkowski and Druffel (2009) present a preliminary method to

detect fullerenes and carbon nanotubes in sediments. These are now produced at industrial scale and can be useful to track environmental changes. This is the first technique that attempts to distinguish environmentally-produced from industrially-produced black carbon in sediments. Wilson and co-workers (2009) report a mass-balance estimation for the presence of the bactericide and fungicide Triclosan, present in many consumer products. It will be interesting to observe time trends of compounds such as these recorded in sediments. Surprises may arise when scientists compare published (laboratory based) degradation rates of many compounds (including pharmaceuticals) and those measured in environmental records. We think that this may become an exciting and useful application of some of the tools described in this issue.

## 3. Conclusions

We believe that this Special Issue is a unique collection of useful studies that can be performed with well dated environmental archives. There are many indicators of anthropogenic impact in coastal ecosystems and we believe that many more are yet to come. New chemicals are produced continuously and released to the environment, with less than a perfect knowledge of their behavior, degradation (if applicable) and impact. In any case, they may be tracers of ecosystem evolution.

Many world regions are lacking sufficient data to assess with confidence anthropogenic impact trends. Effort is needed to cover gaps by producing time series from environmental archives and, where possible, validate them with instrumental records. In polluted areas, this is not a difficult task and the investment needed to produce a reliable record might not be large. Nonetheless, in many places this might be the only option! We also think that this type of study should be incorporated into impact monitoring programs worldwide: if a number of well dated environmental records are assembled with adequate spatial resolution, they will provide the basis for a solid reconstruction of pollution sources, impacts and trends in a region.

This work is not complete. We are convinced that this information is a key to protect the environment. Only by looking at trends we can know where our ecosystems stand, if actions are beneficial, if more actions are needed, and if some actions are useless. It is the responsibility of all scientists to do their best to transmit the key messages to decision-makers. This is not an easy task, but it is worth trying and people with good skills are there to help.

It has been a pleasure for us to compile this issue and we will be thrilled to learn that it triggers some new studies in this field.

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