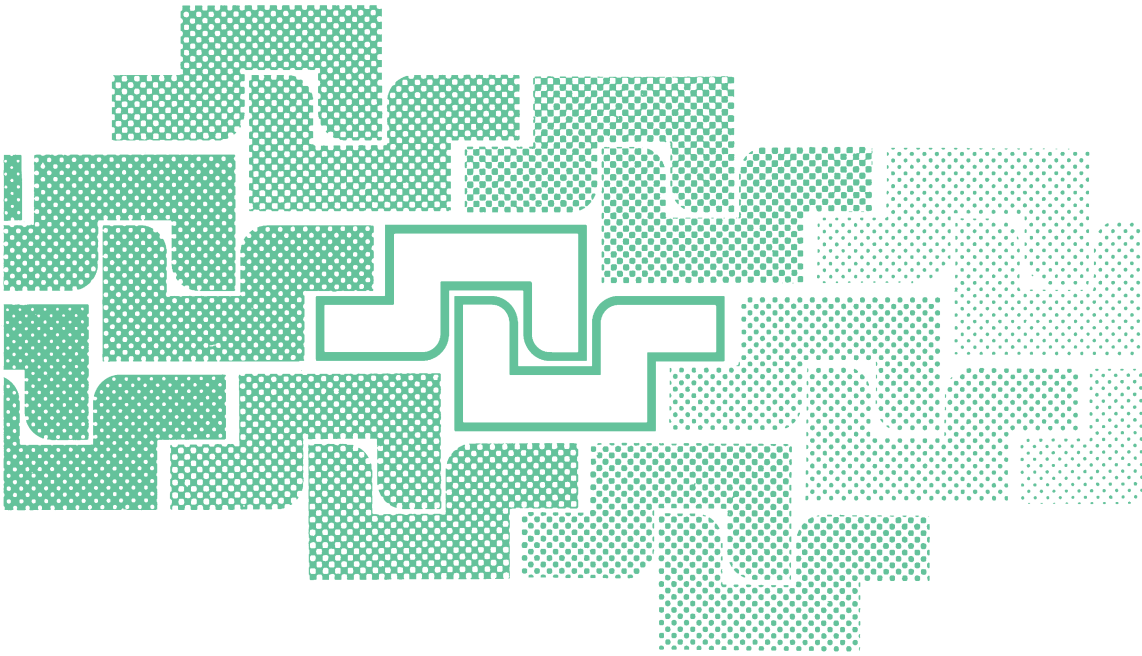

Strategic Management of Marine Ecosystems

Edited by

Eugene Levner, Igor Linkov and Jean-Marie Proth

NATO Science Series

IV. Earth and Environmental Sciences – Vol. 50

Strategic Management of Marine Ecosystems

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Strategic Management of Marine Ecosystems

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Preface

The demand for advanced management methods and tools for marine ecosystems is increasing worldwide. Today, many marine ecosystems are significantly affected by disastrous pollution from industrial, agricultural, municipal, transportational, and other anthropogenic sources. The issues of environmental integrity are especially acute in the Mediterranean and Red Sea basins, the cradle of modern civilization. The drying of the Dead Sea is one of the most vivid examples of environmental disintegration with severe negative consequences on the ecology, industry, and wildlife in the area. Strategic management and coordination of international remedial and restoration efforts is required to improve environmental conditions of marine ecosystems in the Middle East as well as in other areas.

The NATO Advanced Study Institute (ASI) held in Nice in October 2003 was designed to: (1) provide a discussion forum for the latest developments in the field of environmentally-conscious strategic management of marine environments, and (2) integrate expertise of ecologists, biologists, economists, and managers from European, American, Canadian, Russian, and Israeli organizations in developing a framework for strategic management of marine ecosystems.

The ASI addressed the following issues:

- Key environmental management problems in exploited marine ecosystems;
- Measuring and monitoring of municipal, industrial, and agricultural effluents;
- Global contamination of seawaters and required remedial efforts;
- Supply Chain Management approach for strategic coastal zones management and planning;
- Development of environmentally friendly technologies for coastal zone development;
- Modeling for sustainable aquaculture; and
- Social, political, and economic challenges in marine ecosystem management.

Papers presented in this book were submitted by the ASI lecturers and participants. In addition, several papers were invited from the leading scientists in the field. The organization of the book reflects discussions during the meeting. The papers in the first chapter review and summarize problems related to marine ecosystems. They provide the background and examples of environmental challenges and potential solutions. The second chapter provides modeling and mathematical foundations for specific environmental management methods and tools useful for marine ecosystem management. These methods provide a means for coordinating technological, economical, and ecological contradicting demands and offer an exciting prospect for efficient utilization of environmental resources. For example, Strategic Supply Chain management methodology permits detailed characterization of the functional and

structural aspects of ecosystems, assesses the impact of human activity on biological systems, and evaluates practical consequences stemming from the activity. The third chapter presents several papers dealing with integration of political and stakeholder priorities with environmental modeling. A key paper by Pitcher and his colleagues introduces an integrative approach to the strategic management of marine ecosystems with policies based on restoration ecology, and an understanding of marine ecosystem processes in the light of findings from terrestrial ecology. The critical issues include whether past ecosystems make viable policy goals, and whether desirable goals may be reached from today's ecosystem. The final chapter provides another integrated approach for marine ecosystem management that is based on comparative risk assessment and multi-criteria decision analysis. Three papers presented in the chapter illustrate the theoretical foundation of these methods and review applications for a wide range of issues related to sediment management – from highly technical issues (such as selection of optimal technology) to political (assessing value judgment for policy decision makers and stakeholders).

An important objective of the ASI was to identify specific initiatives that could be developed by those in attendance and their broader network of institutions to enhance the progress of environmental risk assessment in developing countries. Consistent with this goal, this book presents the interpretation and perception of issues related to strategic management of marine ecosystems by individual scientists, while also illustrating a wide variety of environmental problems in developing countries.

Eugene Levner, Igor Linkov, and Jean-Marie Proth
August 2004.

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The work presented in this book could not have been started if it were not for the generous support provided by the Scientific and Environmental Affairs Division of the North Atlantic Treaty Organization (NATO). In particular, we would like to thank Doctor Alain H. Jubier for his valuable help.
The staff of INRIA (Institut National de Recherche en Informatique et en Automatique – The French National Institute of Research in Computer Science and Automatic) has been extremely helpful in the organization of the ASI. Missis Christel Wiemert who had the difficult task to assemble the final manuscript and adjust the presentation of most of the papers, have been extremely helpful.
Finally, ASI Directors would like to thank Doctor Igor Linkov for joining them in preparing this book.

Chapter 1

Disturbance of Marine Ecosystems: Problems and Solutions

META-ANALYSIS OF THE RADIOACTIVE POLLUTION OF THE OCEAN

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Abstract
Humans have been altering the marine environment for millennia. Up till now, five critical environmental issues have affected the oceans: over-fishing, chemical pollution and eutrophication, habitat destruction, invasion of exotic species and global climate change. However, one of the major threats the oceans may face in the twenty-first century is radioactive pollution over the second half of the twentieth century.

1. Introduction

The following may be listed among the main anthropogenic sources of radioactive pollution of the ocean:

- Dumping of solid (SRW) and liquid radio-wastes (LRW);
- Pollution from underwater N-explosions;
- Radioactive pollution from land (including river run-off and land-based activities);
- Radioactive fallout from the atmosphere;
- Radioactive pollution originating from accidents (lost N-warheads and radio-emission from thermo-electric generators, sunken craft and ships, falling satellites with radioactive materials, etc.);
- Discharge from ships with N-reactors.

In spite of intensive studying [1,2,3,4], we are still far from having established a really comprehensive inventory of all the anthropogenic radioactive sources of the Ocean. This is mostly due to the fact that much of this data is connected with military activities and remains classified. In India – possibly one of the world's most marine polluted country – for example, the Nuclear Energy Act prohibits the release of information related to nuclear facilities [5]. It looks like only the Russian Federation after the collapse of the USSR have published a more or less complete inventory of radioactive pollution of adjacent seas [6,7]. These circumstances call for some meta-analysis, which will include official as well as unofficial data, for a general ecological understanding of the situation as far as radionuclides pollution of the ocean is concerned.

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2. Radioactive dumping

Beginning in the late 40s and up till 1983, at least 13 countries with a nuclear industry (Belgium, Britain, Germany, Japan, Italy, France, the Netherlands, New Zealand, South Korea, Sweden, Switzerland and the United States) dumped their SRW and LRW into deep parts of ocean (more than 4 km deep). All these countries (excluding the USSR) officially reported dumping up to 1,2 million Ci in radioactive materials [7], including (at time of dumping): USSR – 1 037 kCi; Great Britain - 948 kCi; Switzerland - 119 kCi; USA – 95 kCi; Belgium - 57 kCi; France - 9.6 kCi; the Netherlands – 9.1 kCi; Japan – 0.4 kCi; Sweden – 88 Ci; New Zealand – 28; Germany - 5 Ci; Italy - 5 Ci [2]The largest single radioactive object ever dumped into the Ocean over that period of time was USS *Seawolf* 's sodium-cooled reactor (up to 33 000 Ci) which was scuttled 3000 m deep off the Delaware coast (Maryland) in 1954 [8].

It's possible to use the USSR' dumping activity as the most well known case study [6,7,9]. In 1959, 600 m^3 of low-level liquid waste (LWR) was discharged in the White Sea (20 mCi) and in 1960, the *Lenin* discharged 100 m^3 of LRW (200 mCi) near Gogland Island in the Gulf of Finland. The total activity of LRW dumping is 24 kCi (903 TBq, including 87 TBq for ^{239,240,241} Pu): Baltic Sea - 0.2 Ci (0.0007 TBq); White Sea - 100 Ci (3.7 TBq); Barents Sea - 12153 Ci (450 TBq); Kara Sea - 8500 Ci (315 Tbq). A total of at least 12 335 Ci (456 TBq) of LRW was dumped by the USSR between 1966 and 1991 in the Sea of Japan and near the southeastern coast of the Kamchatka Peninsula.

Low- and intermediate-level SRW dumped over 65 operations between 1967 and 1991 in the White, Barents and Kara seas was enclosed into more than 11 000 metal containers, barges, lighters, and tankers (a total of 17 craft). The total activity of sunken intermediate and low-level SRW, was over 15.5 kCi (574 TBq) in the Kara Sea and 40 Ci (1.5 TBq) in the Barents Sea. The total activity of intermediate and low-level SRW (6868 sunken containers, 38 sunken ships, and over 100 other individual sunken large objects) dumped by the USSR in the Sea of Japan and other areas of the Pacific was 6 851 Ci (254 TBq). SRW comprised mainly contaminated film coverings, tools, personal protective devices, uniforms, fittings, pipelines, activity filter boxes, pumps, steam generators, and various objects contaminated during ship repair work.

Among all RW dumping by the USSR in the ocean, the greatest ecological hazard is presented by objects with SNF (Table 1).

In total, during the 70s and the-80s the former USSR dumped at least 10 reactors with SNF, two shielding assemblies, and 14 reactors without SNF from N-subs and 3 – from icebreakers in the North Atlantic, Arctic and Pacific oceans. The maximum activity of solid radio-wastes that entered seas adjacent to Russia may have been in excess of 2,5 million Ci (at the time of disposal). The main radionuclides were ^{134,137}Cs, ^{90}Sr, ^{239,240}Pu, ^{63}Ni, ^{60}Co.

After more precise calculations and accounts [10,11,12] it was revealed that the activity of the icebreakers' shielded assembly was 3.5 times higher (not 5600 but 19500 TBq), and the radioactivity of the N-subs' reactors dumped in the Kara Sea was 4.8 times lower (not 2.25 but 0.46 million Ci). At the same time it was discovered that data about the dumping of the two N-subs' reactors in the Sea of Japan. was missing from the White Book Therefore the total activity of the N-reactors which were dumped

in the Sea of Japan, was not 1.7 but 396 TBq (940 kCi). According to the new estimate the USSR dumped not up to 2.5 million Ci, but 1.64 million. Because of natural decaying, by the year 2000 there are 0.7 millions Ci in the North Pacific's dumping sites, and 107 kCi (4 PBq) – in the Kara Sea.

TABLE 1. Objects with Spent Nuclear Fuel Dumped by the USSR in the oceans [6,7]

Object	Place, Year	Depth, Meters	Max. activity kCi*	Radionuclides
Compartments of NS's with 4 reactors, 3 containing SNF	Abrosimov Inlet, Kara Sea, 1965	20	1200	Fission products
Shielding assembly of reactor from icebreaker *Lenin* with residual	Tsivolka Inlet, Kara Sea, 1967	49	100	^{137}Cs (50 kCi), ^{90}Sr (50 kCi), ^{238}Pu, ^{241}Am, ^{244}Cm(2 kCi)
Reactor from NS	Novaya Zemlya' Depression, Kara Sea, 1972	300	800	Fission products
NS with two reactors	Stepovoy Inlet, Kara Sea, 1981	50	200	Fission products
Two NS reactors	Sea of Japan, 1978	3000	0,046	Fission products
Core plate from the Reactor of NS No. 714	East of Kamchatka, Pacific, 1989	2500	70	Fission products
Total: 8 reactors, two shield assemblies	Arctic and Pacific	20 – 3000	Up to 2500	86% fission products, 12% activation products, 2% actinides

*- At the time of dumping

In the Arctic Ocean the reactors were dumped mainly in the shallow fjords of Novaya Zemlya at a depth ranging from 12 to 135 m and in the Novaya Zemlya Trough at depths of up to 380 m [6]. Before dumping, the reactor compartments with SNF were filled with a hardening furfurol-based mixture. This filling was supposed to prevent the SNF from being in contact with seawater for up to 500 years. The shield assembly with SNF from the icebreaker was additionally placed in a reinforced concrete container and a metal shell. Between 1992 and 2000 some studies were carried out around several dumping places in the Kara Sea. It was revealed that in the Stepovoy Inlet, Abrosimov Inlet and Tsivolka Inlet, leakage from dumped objects reached worrisome levels of radioactivity – by ^{137}Cs up to 109 kBq/kg dry sediment, ^{90} Sr – 3,8 kBq/kg, ^{60} Co – 3,2 kBq/kg, ^{239,240} Pu – 18 Bq/kg [4]. There is up to 31 Bq/m^3 in the surrounding water, which is six times more than at the surface [13]. As some calculation show, maximum possible release in the Abrosimov Bay may reach 1 TBq per year of ^{137}Cs [14]. Similar investigations carried out in 2003 along the coast of Russia's far eastern Maritime Territory and Sakhalin island revealed elevated concentrations of Cs-137 in two locations at depths of 3,000 m [15]. It means, that in spite of the absence of any immediate danger, it is obvious that the situation is slowly getting out of control. A

special study of the radiological impact of this dumping [16] revealed that it may be dangerous to stay on some Novaya Zemlya beaches adjacent to the fjords used as dumping sites.

Official records from the radioactive dumping into other parts of the ocean are spotty. The figure of 47 dumping sites in the North Atlantic and Pacific [17] is far from the truth. The U.S. officially reported on 30 dumping sites in the Atlantic and Pacific (1946 – 1970). Three of them near the Farallon Isl., off San Francisco Bay, at depths of 90, 900 and 1800 meters, totaling 52 530 55-gallon drums, with a total activity of some 14,7 kCi (540 TBq) [18]. The aircraft carrier *Independence* used as target in the Bikini Atoll's U.S. bomb tests is believed to have been sunk here [19]. 33 998 containers were dumped by the U.S. between 1951 and 1967 in the West Atlantic, with a total radioactivity of up to 77,5 kCi at the time of dumping. Total official U.S. dumping included 52 530 containers with 14,7 kCi [18].

It was not unusual in U.S. and Soviet dumping practice to shoot radio-waste containers with guns when they would not sink. Now after 40-30 years many containers can become corroded and cracked and can disintegrate as, for example, in the Hurd Deep, off the Channel Isl. in UK territorial water (official European dumping site between 1950 and 1963). The UK dumped 50 570 containers with 44,1 kCi beta- and 3,3 kCi alfa-emitters here between 1950 and 1967 [20].

In spite of a special international agreement strongly prohibiting the dumping since 1983 this practice has been continuing up till now in some places, using some loops in the legislation. For example, every year up to 200 tons of low-grade radio-wastes generated by the oil industry are pumped out into the Northern Sea from *Scotoil'*s purification plant in Aberdeen, Great Britain [21].

3. Radioactive pollution due to military accidents

There were about 90 publicly reported military accidents involving nuclear weapons (59 American, 25 Soviet/Russian, four French and one British). Most of them involved N-submarines, but also involved planes, missiles, nuclear-waste storage facilities and surface ships [22,23,24,18,25]. There are four Russian and two U.S. N-submarines (with more than half-dozen reactors and nearly 50 nuclear warheads) already at the bottom of the Ocean. Among them:

- 1963. U.S. NS *Thresher*, Western Atlantic. In 1990 ^{60}Co in sediments were detected near the NS.
- 1968. U.S. NS *Scorpion,* 400 miles southwest of the Azores Isl., Atlantic, with two N-warheads on board. In 1990 ^{60}Co in sediments were detected near the NS.
- 1968. Soviet NS K-129, near Hawaiian Islands, Pacific, more than 6000 m deep, with five N-warheads (in 1974 U.S. *Glomar Explorer* retrieved two N-warheads during operation *Jennifer*).
- 1970. Soviet NS K-8 (*November),* Bay of Biscay, 4680 m deep, with two N- reactors with a total activity of 250 kCi and 10 N-warheads. 1986. Soviet NS K-219 (*Yankee*) with two reactors (activity of 250 kCi) and 32

(50?) N-warheads, 600 miles northeast of Bermuda, 5500 meters deep. The warheads (total activity about 7 kCi) were scattered on the sea floor and have surely been leaking ^{239}Pu.

- 1989. Soviet NS K-278 (*Komsomoletz)* with one reactor and two N-torpedoes (total activity 150 kCi including 2,9 PBq ^{90}Sr, 3,1 PBq ^{137}Cs and 25 TBq for actinides), Norwegian Sea, 1685 m deep. One important difference between this accident and others, including those involving US N-subs, is the threat of accelerated release of radionuclides into the marine environment. The reason is that the *Komsomolets* has a titanium pressure hull. The rate of corrosion is increased a thousandfold when titanium reacts with the ship's steel components in seawater. In 1993 ^{137}Cs concentration near the NS was five times higher (10-30 Bq/m^3) than on surface [4].
- 2002. Russian NS K-141 (*Kursk)* with two reactors (activity up 150 kCi), Barents Sea, 105 m deep (it was later raised).
- 2003. Russian NS K-159 with two reactors (activity about 500 kCi), Barents Sea, 240 m deep.
- In 1985, while NS K-431 (*Viktor)* was having its reactor refueled in Soviet Maritime Territory, Chazhma Bay, an uncontrolled spontaneous chain reaction occurred. A radioactive fallout occurred on the water surface for up to 30 km, and the total release of radioactive substances into the atmosphere was at about 2 000 kCi for short living gases and 5 000 kCi (185 PBq) for other fissions, mostly iodine isotopes, ^{60}Co, ^{54}Mn and other activation radionuclides [26]. A large part of the water area of Ussury Bay was radioactively contaminated. One hour after the explosion, the activity of short-living radionuclides in the seawater reached 2 Ci/l. The radioactivity of bottom sediments is mainly due to ^{60}Co and to ^{137}Cs.

At least five other accidents involving N-subs and ships resulted in the release of radionuclides into the ocean:

- 1966. Soviet NS, NS base in Poliarny, Kola Bay, Barents Sea;
- 1971. U.S. NS SSN-583 (*Dase)*, Western Atlantic;
- 1986. Soviet NS K-175, Kamran' Bay, South China Sea;
- 1989. Soviet NS K-192 (Echo-2), Barents Sea;
- 1989. Soviet NS, Ara Bay, Barents Sea; released up to 2 kCi (74 TBq) LWR;
- 1993. Russian icebreaker *Arctic,* Kara Sea;
- 1997. Russian vessel *Imandra* (floating storage for SNF), Kola Bay, Barents Sea.

Sunken N-bombs are one of the serious sources of radioactive pollution. Although this information was always kept top-secret (and never officially reported), several (from many?) cases like this are known [27,28,29,25]:

- 1950. A U.S. B-36 dropped the N-bomb off the coast of British Columbia;
- 1952. U.S. C-124 "*Globemaster*" transport aircraft with three N-bombs and "nuclear capsule" jettisoned two of the bombs east of Rehobeth, Delaware, and Cape May, Wildwood, New Jersey. In spite of an intensive search, they are still there at the bottom of the ocean;1956. the U.S. Air Force lost a

bomber with two nuclear-weapon cores in their carrying cases over the Mediterranean Sea;

- 1958. A U.S. B-47 bomber collided with another jet near the U.S. Air Force's base on Tybee Island, Georgia; An H-bomb was jettisoned into water several miles off the mouth of the Savannah River in Wassaw Sound off Tybee Beach, Georgia. In spite of an intensive search it was never found.;
- 1959. A U.S. Navy P-5M aircraft carrying a nuclear depth charge (without fissile core) crashed into Puget Sound near Whidbey Island;
- 1965. U.S. A-4E bomber *Skyhawk* loaded with a N-bomb B-43 rolled off an elevator on aircraft carrier *Ticonderoga* (CVA-14) and fell into the sea several miles off the Ryakyu Islands, Japan;
- 1966. A U.S. B-52 aircraft carrying four multi-megaton N-bombs crashed into an Air Force KC-135 refueling tanker and dropped all its weapons near Palomares, Spain (two of the bombs off shore; two bombs ruptured, scattering radioactive particles over 100 $km^{2,}$ The 3rd bomb landed instantly, and the 4th was lost 19 km off the coast (It was found after 870 days of intensive search, involving about 80 ships and thousands of servicemen);
- 1968. A U.S. B-52 aircraft with four N-bombs crashed 7 miles south of the Thule Air Force Base, Bylot Sound, Greenland; ^{239,240,241}Pu from the bombs spread over the ice (up to 11 TBq) and sank to the bottom (^{239,240,}Pu concentration in sediments in 2000 had reached 7600 Bq/kg);
- 1977. A N-warhead was dropped into the ocean from Soviet NS K-171 (*Delta-1)* in the Western Pacific, near the Kamchatka Peninsula; it was successfully found and recovered.

Special assessment [30] revealed that 27 types of N-sub failure at sea or in base, 3 types of failure of other ships and 4 types of failures connected with storing and transporting nuclear weapons have radiological consequences.

At least in one case the ocean was polluted by a missile: in 1962 a nuclear test device atop a Thor rocket booster fell into the Pacific near Johnston Atoll.

4. Pollution from underwater N-explosions

Underwater and close-to-surface (above-water) N-explosions are a very serious source of radioactive contamination of the Ocean. There are several places where such pollution occurs:

- Bikini atoll, Marshall Islands (one underwater, 13 above-water U.S. N-explosions);
- Enewetak atoll, Marshall Islands (two underwater, 18 above-water U.S. N-explosions);
- Pacific Ocean (two underwater U.S. N-explosions);
- Christmas Island, Polynesia (several U.S. and British underwater and above-water N-explosions);

- South Atlantic, between 38^0 and 49^0 S.L. and between 8^0 and 11^0 W.L (three U.S. above-water N-explosions);
- Moruroa and Fangataufa atolls, Tuamotu Archipelago, French Polynesia (four above-water French N-explosions).
- Chemaya Bay, South-Eastern Barents Sea (three underwater and three above-water USSR N-explosions).

Now several thousand square kilometers of the bottom of the South Barents Sea are the most Pu-polluted place in the ocean – up to 15 kBq/kg in sediments [31]. There are also here ^{241}Am, ^{137}Cs, ^{90}Cr, ^{155}Eu and other radionuclides (Table 2).

TABLE 2. Distribution of Radionuclides (Bq/kg dry weight) in Surface Bottom Deposits of the Southeastern Barents Sea, 1992 [32]

	Chernaya Bay	Karskie Vorota strait	Pechora Gulf	Of Vaygach Island
^{241}Am	2622.0	0.0	0.0	0.0
^{137}Cs	1444.2	9.4	23.8	6.7
^{60}Co	618.0	0.0	0.0	0.0
^{155}Eu	344.4	0.0	0.0	0.0
^{212}Pb	298.5	25.1	66.2	24.1
^{212}Bi	260.9	0.0	22.8	24.3
^{226}Ra	206.4	62.2	0.0	0.0
^{214}Pb	170.0	30.1	45.8	27.7
^{224}Ra	139.9	7.6	22.4	26.9
^{214}Bo	131.7	26.5	39.4	22.6
^{208}Ti	89.6	8.8	19.2	8.6
^{228}Ac	33.5	18.7	51.3	16.6

The total amount of the radionuclides concentrated in the Chernaya Bay area is about $3x10^{12}$ Bq or 81 kCi [33]. Some of them could be diffused all over the Eastern part of the Barents Sea over the course of this Century with a potential negative impact on Norwegian and Russian fisheries and marine life. Through differences in the concentration of Pb, Cs, Pu, Co radionuclides in the sediment profiles, it is possible to calculate when the pollution started (depths of 10 to 15 cm), and when it maximized (3-4 cm depth [34]). Even 40 year after the N-explosions, levels in bottom sediments here were up to 200 mCi/kg ^{239,240}Pu, and in water – ^{137} Cs up to 200 Bq/m^3, ^{90} Sr up to 140 Bq/m^3 [4]. Chernaya Bay may now be one of the most radioactive polluted places in the Ocean, only comparable with the waters of the Enewetok atoll.

5. Radioactive fallout from the atmosphere.

Atmospheric deposition of radionuclides originating from more than 500 atmospheric N-tests and N-industry activities in the 1960s and 1970s were the main sources of radioactive pollution of the Ocean. Before 1980, the following was released into the atmosphere from N-tests [29,25]: ^{140}Ba – 732 Ebq; ^{131}J – 651 Ebq; ^{141} Ce – 254 Ebq; ^{3}H

– 240 Ebq; ^{103}Ru –238 Ebq; ^{95}Zr – 143 Ebq; ^{91}Y – 116 Ebq; ^{89}Sr – 91.4 Ebq; ^{144}Ce – 29.6 Ebq; ^{106}Ru – 11.8 Ebq; ^{137}Cs – 0.912 EBq, ^{90}Sr – 0.604 Ebq, $^{239, 240, 241}$Pu – (0.151 – 0.375) Ebq, etc, for an overall total of more than 2 510 Ebq. Although the USSR, the USA, France and Great Britain stopped atmospheric tests after 1963 (China – after 1983), the fallout of fission residuals (mostly ^{137}Cs, ^{90}Sr, ^{239,240}Pu, ^{131}J, ^{14}C, ^{3}H) with an activity of many millions Ci from the atmosphere to the Ocean will continue for many centuries to come.

The second a source of radioactive pollution of the ocean from the atmosphere after N-tests is accidental and regular discharges from Nuclear Power Plants. If N-test pollution is steadily declining with time, the level of NPP pollution due to annual emission is increasing. Some calculations [35] indicate that due to the activities of the 2000 NPPs (now – 440) that produce about 1000 GWt annually the individual effective dose will soon reach 1 mSv annually.

The Chernobyl catastrophe (the atmospheric discharge was about 50-250 MCi) immediately resulted in the serious radioactive pollution of the North Atlantic (Baltic, Norwegian, North and Irish Seas) and the Mediterranean (especially the Black Sea). ^{134}Cs concentrations in the Baltic's waters were up to 6 000 Bq/m^3, in dry alga *Fucus vesiculosus* they reached 4900 Bq/kg (^{131}J - up to 29 kBq/kg), ^{137}Cs and in dry plankton they came up to 2500 Bq/kg [4]. These characteristics are three times higher than pre-Chernobyl levels. In the Black Sea the highest ^{137}Cs radioactivity from Chernobyl was about 500 Bq/m^3, i.e. 30 times higher than pre-accident levels [36]. It must be noted that in the days and weeks following the catastrophe the levels of tens of other radionuclides were hundreds to thousands of times higher than the level of ^{137}Cs: this was bound to have an enormous negative impact on the marine environment.

The atmospheric radioactive fallout which was collected by pack and floating sea-ice can be transported over long distance, for instance from the Kara shelf to the waters off Greenland and Norway [4].

6. Radioactive pollution from land

The man-originated radioactive flow from land to the seas includes two main sources: river runoffs and direct discharges from land-based activities.

Radioactive river runoff to the Ocean mainly consists of atmospheric fallout and direct radioactive discharges into the rivers. Atmospheric fallout results from N-tests, Chernobyl and other radioactive catastrophes, and is also due to "permissible" everyday discharges into air from up to 440 commercial Nuclear Power Plants, from hundreds of scientific N-reactors and from several reprocessing facilities. As a result the soils of the Northern Hemisphere contain ^{137}Cs at a level of about 40 mCi/km^2, and ^{90}Sr at about 30 mCi/km^2, on average. These radionuclides collected by catchment areas are slowly moving to the ocean. Entries of ^{90}Sr and ^{137}Cs to the Barents Sea from river runoff between 1961 and 1989 were about 6 kCi (200 TBq). The total entry of ^{137}Cs and ^{90}Sr to the Barents Sea from the atmosphere with global fallout of the products of nuclear explosions over the same period is estimated at approximately 100 kCi (3700 TBq). Calculations for the Kara Sea give corresponding values of 33 kCi (1200 TBq) and 70 kCi (2600 TBq).

During the production of the USSR's nuclear arsenal (up to 40 000 N-warheads) three USSR uranium/plutonium plants, "MAYAK" in South Ural (Tobol – Irtysh – Ob' river system), Siberian Chemical Combine in Western Siberia (Tom' – Ob' river system), and Mining Chemical Combine in Eastern Siberia (Enysey river system) produced up to 2.71 billion Ci LRW. From these 1.61 billion Ci are stored in surface water bodies. Sooner or later,a considerable part of these radionuclides will go to the Arctic Ocean due to the Northern Asia Slope. According to expert estimate, the radioactive discharge to the Ob-Irtysh river system alone was up to 63 PBq [4]. There are concentrations of these "weaponry" radionuclides in the sediments of the Enisey and Ob' deltas: up to 100 Bq/kg by ^{137}Cs, and up to 16 Bq/m^3 by ^{90}Sr (in sediments). In the 1960s and 70s, the Kara Sea waters had ^{90}Sr up to 85 Bq/m^3, ^{137}Cs up to 40 Bq/m^3 and ^{239,240}Pu up to 16 mBq/m^3 [4]. It is reasonable to calculate that for their production of 30 000 N-warheads, the USA must have produced similar amounts of LRW (about 2 billion Ci). North American lakes Ontario and Erie were radioactively contaminated from the West Valley N-reprocessing plant in 1972. 400 millions m^3 from a liquid radioactive uranium mill tailing were sent to Church Rock, New Mexico after breaking the dam in 1979 [8]. Over their 40 years of producting fissile material for the U.S. nuclear arsenal, the Hanford Engineering Works discharged many billions of m^3 of radioactive water directly into the Columbia River. The same phenomenon occurred at the Savannah River production plant in the southeast of the USA, and at the Sequoiah Fuel Corp. uranium processing plant, which contaminated the Arkansas River. Through the rivers, a considerable part of these "military" radionuclides were transported to the ocean.

Mining is an additional source of inland radioactive water pollution. It never released any new manmade radionuclides, but introduced large amounts of natural uranium, radium (like in the Pechora River, North Ural, Russia), and thorium isotopes from the deep geological formations into surface ecosystems.

Direct discharges from land-based activities even caught the attention of the UN General Assembly, which in December 1996 adopted Resolution 51/189 about the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities.

France and Great Britain discharged large amounts of LRW to the ocean, from Sellafield in England (the nuclear fuel production and reprocessing facility) and from La Hague (France's similar plant in Normandy) through long pipes (in La Hague - 1700 m from the shore): 1.1 million Ci ^{137} Cs, 0.5 million Ci ^{241} Pu, 0.5 million Ci ^{3} H, about 0.3 million Ci ^{106} Ru, about 0.5 million Ci of other radionuclides [11]. The peak of the Sellafield beta-nuclides discharge was reached in 1975, when a total of more than 9000 TBq (including more than 5200 TBq by ^{137}Cs) were released. Discharges by alpha-emitters peaked in 1973– up to 180 TBq. Between 1966 and 1984, Sellafield discharged 20 821 TBq (566 kCi) ^{241}Pu and up to 631 TBq ^{239} Pu [37]. In 1991, a total of were 100 Ений for ^{238}Pu, 610 TBq for ^{239,240}Pu, and 945 TBq for ^{241}Am [25] were discharged. In 1980-1984 ^{137} Cs concentration in Scotland's coastal waters was up to 400 Bq/m^3 [4]. The Irish Sea sediments near Sellafield had ^{137}Cs up to 5.5 kBq/kg, ^{90} Sr – 2 kBq/kg, ^{239,240} Pu – 34.8 kBq/kg, ^{238}Pu – 9.6 kBq/kg, ^{241}Am – 2.2 kBq/kg [4,38,39]. Between 1968 and 1979 about 180 kg of Pu was discharged from Sellafield. In 1983 the GB Ministry of Environment closed off more than 20 km of the beach area near Sellafield

due to dangerous levels of radioactive contamination [40]. In 1999 - 2000 Sellafield discharged about 130 GBq alpha-nuclides, and La Hague – 40 GBq [29]. In a single year, La Hague discharges five times more ^{129}O than was released during all N-tests worldwide [41].

Till now radioactive discharge from Sellafield and La Hague have polluted not only the Irish Sea and the Channel, but also Northern Seas like the Barents and even the Kara Sea and could have contributed about 200 kCi (7400 TBq) - up to 7% of the whole anthropogenic radionuclides budget here: up to 20% ^{137}Cs and 30% ^{90}Sr from Sellafield ended up in the Barents Sea [42]. Since the 1990s, detectable increases in the concentrations of $^{127, 129}$J, and 99Tc have been revealed in the North Sea near Norway [43,44,45]. In 2003 ^{99}Tc (up to 20 Bq/Kg) were found in smoked and fresh farmed salmon sold in Sweden's six leading supermarkets [46]. in 2001, The Nordic Council (Finland, Sweden, Denmark, Norway, Iceland) wrote to Britain over continuing radioactive emissions (especially ^{99}Tc and ^{125}Sb) from Sellafield. In 2001 Norway initiated a lawsuit against Britain, insisting that Sellafield's discharge release represents a serious threat to the Norwegian Fishing industry [47]. Official sources (review see: [4]) insist that Sellafield and La Hague discharged no more than 1.1 mln Ci ^{137} Cs, 0.5 mln Ci 241 Pu, 0.5 mln Ci ^{3}H, 0.3 mln Ci ^{106}Ru and more than 0.1 mln Ci other long-living radionuclides into the North Atlantic

There are three Indian re-processing plants use water from THE Arabian Sea as a secondary coolant, AND discharge radioactive wastes back into the Sea (*Trombay* in Bombay Harbour and *Tarapur*, about 80 km to the North West). These places are called the "radiation coast" due to high levels of radioactivity directly discharged into the sea by these reprocessing plants [48]. The third Indian reprocessing plant, *Kalpakkam*, is located on the Tamil Nadu shore, on the Bengal Bay coast. Due to state secrecy it is impossible to detect the real scale and radionuclide composition of the Indian Ocean's pollution, but it can reasonably be supposed that it may compare with the North Atlantic's pollution.

Numerous NPPs located on the shores of the the USA, Great Britain, South Africa, Japan etc, regularly discharge radionuclide. There are some examples of illegal discharges or LRW dumping from such NPPs. One of the latest happened in October 2002 on Scotland's North Sea coast from NPP *Torness* [49].

There are three coastal radioactive waste storage facilities for Russian N-sub SNF assemblies (Andreev Bay, on the Barents Sea; Vilyuchinsk, on the Okhotsk Sea and Bol'shoi Kamen', on the Sea of Japan). Beginning in the 60s, some nuclear fuel assemblies were just set right on the ground without even a roof [50,51]. The total activity of the SNF in the Kola Peninsula is about 10 000 kCi [52]. All such coastal N-installations are potential (and real) sources of serious local pollution. In 1996-1998 the sediment of the Kola Peninsula water contained: ^{137} Cs up to 115 Bq/kg; ^{60} Co – up to 74 Bq/kg, ^{239,240} Pu up to 9 Bq/kg [53]. The Kola peninsula N-icebreakers base annually discharges about 1.6×10^{7} of ^{137}Cs, 7.6×10^{7} of ^{90}Sr and even some Plutonium –1998 figures reached 70 mBq/m^3 ^{239,240} Pu, which is 5 to 6 times higher than local background concentration [53]. The amount of ^{152} Eu, $^{134, 137}$ Cs, ^{60} Co in the algae *Laminaria digitata* and *Fucus vesiculosus* is several times higher than in other places along the Barents Sea shelf [53]. At least seven types of failures on coastal objects are connected to radioactive waste storing and conditioning [30].

7. Pollution from Radioisotope Thermal Generators

There are two types of thermal radioisotope generators: the more powerful are based on up to 90% ^{235} U enriched N-reactors (for satellites), and the others are Radioisotope Thermal (Thermoelectric) Generators (RTGs), which are used to supply power to lighthouses and meteorological posts and in deep sea acoustic beacon signal transmission, and also for satellites. RTGs have either a ^{90}Sr or a ^{238}Pu core. Since 1960, nine models of RTGs have been developed in the USSR (for a total number of up to 1500 RTGs with a total ^{90} Sr activity of up to 1.5 Ebq). The most common is the Beta-M type (230 Watts of power, 35 to 40 kCi of activity). The radioactivity of an RTG at a distance of 0.5 meters is up to 800 roentgens per hour.

There are at least six cases when RTGs were sources of radioactive sea pollution [54,22,55,56]:

- 1987. An RTG was lost at sea during transportation near the eastern coast of Sakhalin Island, in the Okhotsk Sea, with an activity of up to 750 kCi (27.8 PBq);
- 1997. An RTG was lost at sea during transportation near the eastern coast of Sakhalin Island, in the Okhotsk Sea, with an activity of about 35 kCi (1.3 PBq);
- 2003. The disintegrated core of an RTG (up to 40 kCi or 1.5 PBq) was found in the waters of the Finnish Bay, in the Baltic Sea;
- 2003. Two disintegrated RTGs were found underground on the coast of the Laptev Sea, Yakutia;
- 2003. RTG Beta-M type # 255 was found completely dismantled in Olenya Bay lighthouse # 414.1, the Kola Harbor; the radioisotope core was found in the water near the shore, 1.5 to 3 meters deep.
- 2003. RTG Beta-M type # 256, which powered lighthouse No 437 was found completely dismantled on Yuzhny Goryachinksy island, the Kola Harbor; its radioisotopes core could not be found.

Satellite RTGs usually have a plutonium core. The following are among the accidents involving satellites with RTGs falling into the ocean :

- 1964. U.S. satellite *Transit 5NB-3*, with SNAP-9A RTG, ^{238} Pu 16 kCi (629 TBq); burned up upon reentering the atmosphere over the West Indian Ocean north of Madagascar;
- 1968. U.S. *Nimbus B-1*, with two SNAP-19 RTGs, ^{238} Pu total up to 1265 TBq, in the Santa Barbara Channel, on the Californian shore (was recovered);
- 1970. Parts of U.S. station *Appolo-13* with SNAP-27 RTG, ^{238} Pu up to 1.63 PBq, re-entered the atmosphere over the South Pacific and fell into the ocean south the Fiji Islands, in the vicinity of the Tonga Trench;
- 1973. USSR satellite with RTG, into the Western Pacific north of Japan;
- 1983. Part of the USSR satellite *Cosmos-1402* with reactor core ^{235} U, ^{90} Sr and ^{137} Cs (up to 1 PBq) re-entered the atmosphere and fell into the South Atlantic, 1600 km East of Brazilia;
- 1996. Russian space station *Mars-96*, 18 RTGs ^{238}Pu total activity 174 Ений

(4.7 kCi), fell into the South Pacific between the Easter Isl. and the Chilean shore.

RTGs are not such an important source of radiation compared with many others, but they can be a reason for heavy local pollution in any part of the Ocean.

8. Sunken ships with radioactive materials

In 1996 six members of the U.S. Congress sent President Bill Clinton a letter expressing deep concern over the existing practice of shipping radioactive waste by sea [57]. There are at least three cases when commercial cargo ships transporting radioactive material sank:

- 1984. Cargo "Mont-Louise" (France), transporting 350 t uranium hexafluoride from France to the USSR (30 containers), sank after a collision with a ferry 15 km off the coast of Ostende (where the sea is 15 m deep). All the containers were successfully found and raised within the next 40 days.
- 1997. Cargo MSC "Karla" (Panama) transporting 5 cesium chloride sources (^{137}Cs up to 9 kCi or 330 TBq) from France to the USA ran into heavy sea, split in two and sank 70 nautical miles off the Azores islands where the sea is 3 000 m deep.
- August 2003. Cargo "Sealand Express" (US Ship Management) transporting 56 t uranium dioxide ("yellow cake") from South Africa to the US ran aground in Table Bay about 150 m off Sunset Beach in Milnerton, Cape Town [58]. The shipment was headed to a uranium processing plant in Newport News, Virginia. AngloGold Co., a subsidiary of London-based Nuclear Fuels Corporation (Nufcor) transport a thousand tons of uranium oxide (a by-product of gold mining) from South Africa each year.

Statistically, there is one serious accident during sea transportation for each 10 million ship/km [59]. The world's annual maritime traffic of radioactive materials is about 3 to 5 million ship/km. It means that one serious shipwreck involving radioactive material may occur every 3 to 4 years.

9. Discussion

ADD – dangerous consequences of previous irradiations.
Up to 10 000Bq/kg in plankton everywhere from underwater N-explosions/
And 2500 Bq/kg in the Finnish Bay several weeks after the Chernobyl catastrophe.

The above-mentioned facts are only a part of the real picture of radioactive marine pollution from anthropogenic sources.

Emission of radionuclides from underwater sources instrumentally detected in a radius of 10 to 70 km after 30 years, which represents several hundred meters to several km per year. Some data indicate that the steel corpus of the nuclear warhead has now disappeared and that ^{239}Pu is escaping into the Norway Sea. This process of

plutonium escape could create a zone of contamination by ^{239}Pu corrosion products (which are both highly active and chemically toxic). 6.4 kilograms of ^{239}Pu from two N-warheads (total activity at 430 Ci) are enough to poison the local fishing grounds in the Norway Sea.

The common feeling [1,3,11,13,60,61,62,4] that the level of anthropogenic radioactive pollution of the world's ocean is not so serious is only justified according to modern average levels of ^{137}Cs concentration in surface water 2-6 Bq/m^3, ^{90} Sr concentration at 1 – 4 Bq/m^3, ^{239,240}Pu concentration at 5 – 30 mBq/m^3 ., ^{241}Am – 1-2 mBq/m^3. It is well known that the total radioactivity of naturally occurring radionuclides ^{40}K, ^{226}Ra, ^{232}Th and ^{210}Po in the ocean is many times higher than that of anthropogenic ones. But it would be a mistake to conclude that the level of anthropogenic radioactive pollution of the Ocean is "negligible". Natural background radiation is like a ship filled to the brim with water. The tiniest additional drop (hundreds of thousands of times smaller than the volume of water in the ship) can initiate an overflow. This analogy leads to the conclusion that even comparatively small additional amounts of manmade radionuclides in the ocean can have some negative consequences for ecosystems and humans. Through bioaccumulation, manmade radionuclides in the water can concentrate in marine animals and plants up to many thousands of times (Table 3).

TABLE 3. Maximal Concentration factors for radionuclides (concentration in tissues compared with concentration in water) in some Marine Organisms [63,11,25]

	Invertebrates	Fish
P-32		100 000
Zn-65	50 000	87 200
^{210}Po	50 000	26 500
Cs-137	200	17 580
Fe-55	30 000	3 000
^{241}Am	20 000	2 500
^{210}Pb	837	1600
Cm	30 000	3000
Pu	10 600	300
^{226}Ra	1000	100
^{3}H	10	10

From a biological point of view, it is impossible to carry out an exhaustive study of all the consequences, such as bio-concentration for all marine ecosystems, and it is impossible to study the specific radiotoxic impact of each radionuclide on all species. What is known about Tc influence on many thousands of marine species of the North Atlantic? But namely Tc has now become a more detectable pollutant originating from Sellafield. Outside the food-chain concentration, there are also numerous natural processes including horizontal and vertical water transportation, different sediment concentrations, resuspensions, etc. All these can result in manifold concentration of different radionuclides in some unpredictable places.

Another important reason for disillusion about the safety of existing ocean radioactive pollutions is a methodologically wrong conclusion on safety based on statistical average data. Like averaging temperature for hospital patients has nothing to

do with each particular person's real health condition, the average concentration of radionuclides in the ocean has nothing to do with the real radiological situation in particular places. Dumping and lost radioactive objects, including nuclear reactors and N-warheads, can and do create thousandfold concentration in hundreds of places all over the ocean.

The third reason for serious concern about the ocean's radioactive pollution is the lack of real data and the continuing secrecy on the subject. The known cases of radioactive pollution seem to be just the tip of the iceberg. Who could predict 20 years ago that the USSR would secretly dump radioactive waste whose total activity reaches several million Ci in the Arctic seas? When Russia published all the data and called for all other countries to open their secret files [6,7] they never did. In the words of Ph. M. Klasky, director of the Bay Area Nuclear Waste Coalition (California, USA) : "*For years, we have asked ... to conduct a survey so that we know how much radioactive waste is being produced ... Without this information and oversight, abuses do occur*" [64].

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MARINE PROTECTED AREAS: A TOOL FOR COASTAL AREAS MANAGEMENT

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Abstract

Marine biodiversity is threatened by human impact. Though few marine species are regarded as being extinct due to Man, many species are critically endangered (e.g. the monk seal Monachus monachus), endangered (e.g. the Mediterranean giant limpet Patella ferruginea) or vulnerable, i.e. dwindling rapidly, although not threatened with extinction in the immediate future (e.g. the large mollusk Pinna nobilis). There are also threats to ecosystems (ecodiversity), such as, in the Mediterranean, the Lithophyllum byssoides rim and the seagrass Posidonia oceanica meadow. Marine Protected Areas (MPAs) were initially established to protect biodiversity via the removal of human exploitation and occupation. However, since the 1970s, the notion of MPA has moved on to a more general concept of nature conservation, then to a more dynamic one of nature management, within the framework of sustainable development. Today, the aims of MPAs are therefore six-fold: nature conservation, public education, reference areas for scientific research, tourism, export of fish eggs, larvae and adults to adjacent areas and finally management of the various uses of the sea (e.g. commercial fishing, recreational fishing, pleasure boating and tourism) in such a way that they do not conflict with each other or with conservation aims. Mediterranean MPAs, especially the Port-Cros National Park, illustrate the fact that they are rather characterized by the management of human activities than by a set of prohibitions and that there is no negative interaction between biodiversity conservation and artisanal fishing (i.e. small-scale commercial fishing), at least in the way it is done (i.e. with additional constraints to general regulations: mesh size, prohibition of trawling and long-lining, etc.). Consequently, MPAs are generally of benefit to the economy (e.g. commercial fishing and tourism industry), not only within MPAs but also in adjacent areas. They therefore constitute a powerful tool for integrated coastal management.

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1. Introduction

The erosion of biodiversity (e.g. species diversity and ecosystem diversity) constitutes a major concern, both in the terrestrial and marine realm. The establishment of protected areas banning human activities was, from an historical point of view, the earliest response to their impact.

Today, especially with regard to the marine environment, the approach has totally changed. In the present paper, on the basis of examples mainly drawn from the experience of a Mediterranean Marine Protected Area (MPA), the Port-Cros National Park, we show that the efficiency of MPAs does not lie in the *a priori* prohibition of human activities but in their management, in such a way that they no longer conflict with each other or with nature conservation goals.

In the mind of the general public, MPAs are still often perceived as areas preserved from human presence. Here, we show that they actually constitute powerful economic tools, both for artisanal (i.e. small-scale) commercial fisheries and for the tourism industry.

2. The need for Marine Protected Areas

2.1. Marine biodiversity

Biological diversity (biodiversity) means the variety among living organisms from all sources including, *inter alia,* terrestrial, marine and other aquatic ecosystems and the complexes of which they are part. This includes: diversity within species, diversity between species, genera, families, phyla, etc., diversity between ecosystems, diversity between landscapes and functional diversity. Ecosystem diversity is often referred to as "**ecodiversity**". Within species diversity, one may distinguish **point diversity** (species number within a sample), **α diversity** (species number within a habitat or ecosystem in a given region), **β diversity** (the species turnover between adjacent habitats or sections of coastline), **γ diversity** (the number of species of a region, either defined on a political, geographical or biogeographical basis) and **ε diversity** (the number of species of a large geographical area, e.g. the Mediterranean basin) [62, 63]. There is no link between these levels of species diversity. For example, α diversity may be high and γ diversity low. Human impact may locally increase α diversity while diminishing γ diversity [81].

The overwhelming value of biodiversity, as an indication of environmental health and for the functioning of the biosphere, is now widely recognized, not only by academic scientists, but also by the mass media, decision makers and public opinion [82, 116].

Unfortunately, marine biodiversity has received only a very small fraction of the attention devoted to terrestrial environments. Not only do the species definitely recorded clearly represent only a small part of those that actually occur [46, 88, 107, 108], but the present status (how many? where? on the increase or on the decrease?) of most of them is poorly known [20, 23], with the exception of a few emblematic taxa (e.g. sea mammals, sea turtles, seagrasses, some fishes).

Rating the relative importance of human impact on biodiversity requires that the time needed for the impact to be reversed be taken into account (Alexandre Meinesz *in* [24]): one day to one month, one month to one year, one year to ten