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Marine environmental protection, sustainability and the precautionary principle

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Abstract

The global oceans provide a diverse array of ecosystem services which cannot be replaced by technological means and are therefore of potentially infinite value. While valuation of ecosystem services is a useful qualitative metric, unresolved uncertainties limit its application in the regulatory and policy domain. This paper evaluates current human activities in terms of their conformity to four principles of sustainability. Violation of any one of the principles indicates that a given activity is unsustainable and that controlling measures are required. Examples of human uses of the oceans can be evaluated using these principles, taking into account also the transgenerational obligations of the current global population. When three major issues concerning the oceans: Land based activities, fisheries and climatic change are examined in this way, they may easily be shown to be globally unsustainable. It is argued that effective environmental protection can best be achieved through the application of a precautionary approach. © 1999 Published by Elsevier Science Ltd on behalf of the United Nations. All rights reserved.

Keywords: Sustainability; Precautionary approach; Environmental protection

1. Introduction

The world's oceans comprise the largest habitat on earth. Over 70% of the surface of the earth is covered by seawater to an average depth of 3.8 km. The total volume of this water is around 1.3 billion cubic kilometres and comprises around 0.24% of the total mass of the earth (Angel, 1997). Human impacts upon oceanic systems both direct and indirect are set to increase in the future. According to the latest estimates, global population is projected to grow from the five billion recorded in 1987 to six billion in 1999 and to continue to increase until at least the middle of the next century (UNFPA, 1998). The world's population is located predominantly in coastal regions. Over 65% of the cities with a population greater than 2.5 million are found near the coast: more than half the population of the United States lives within 80 km of the sea, for example (OECD, 1991). Urbanisation is projected to increase in the future (UNEP, 1993) with coastal populations likely to increase at higher relative rates than the population in general. By 2050 it was estimated that 60% of the global population will live within 60 km of the sea (Elder and Pernetta, 1991). Most human exploitation of the oceans concentrates on resources in coastal areas and the areas of continental shelf underlying water extending to 200 m in depth. It is in the fertile coastal and continental shelf regions that many of the impacts of human activities are currently evident and where, unless measures are taken, they will continue to become manifest.

Five major problems facing the global oceans were identified (Costanza et al., 1997): overfishing; ocean disposal of wastes and spills; destruction of coastal ecosystems; land based sources of pollution and climate change. These problems can be analysed in various ways. Simple documentation of the scope and scale of these problems is relatively easy at a number of levels. On a global scale, the extent of threatened and/or degraded coastal resources can be represented cartographically (see Fig. 1) in relation to, for example, pollution. A more focused approach based upon local/regional chemical analysis or upon fish population studies may identify that changes have occurred. It is unlikely, however, that this will be able to resolve either the full scale or the full significance of those changes.

Economic models were developed with the intention that the values derived from them can be used to assist in policy judgements and decisions. These efforts are at an early stage and the figures generated to date demonstrate the high value of the oceans to humans. However, because of uncertainties attached to both present and likely future values of ecosystems, these efforts ultimately allow only the most general conclusions to be reached concerning the future direction of

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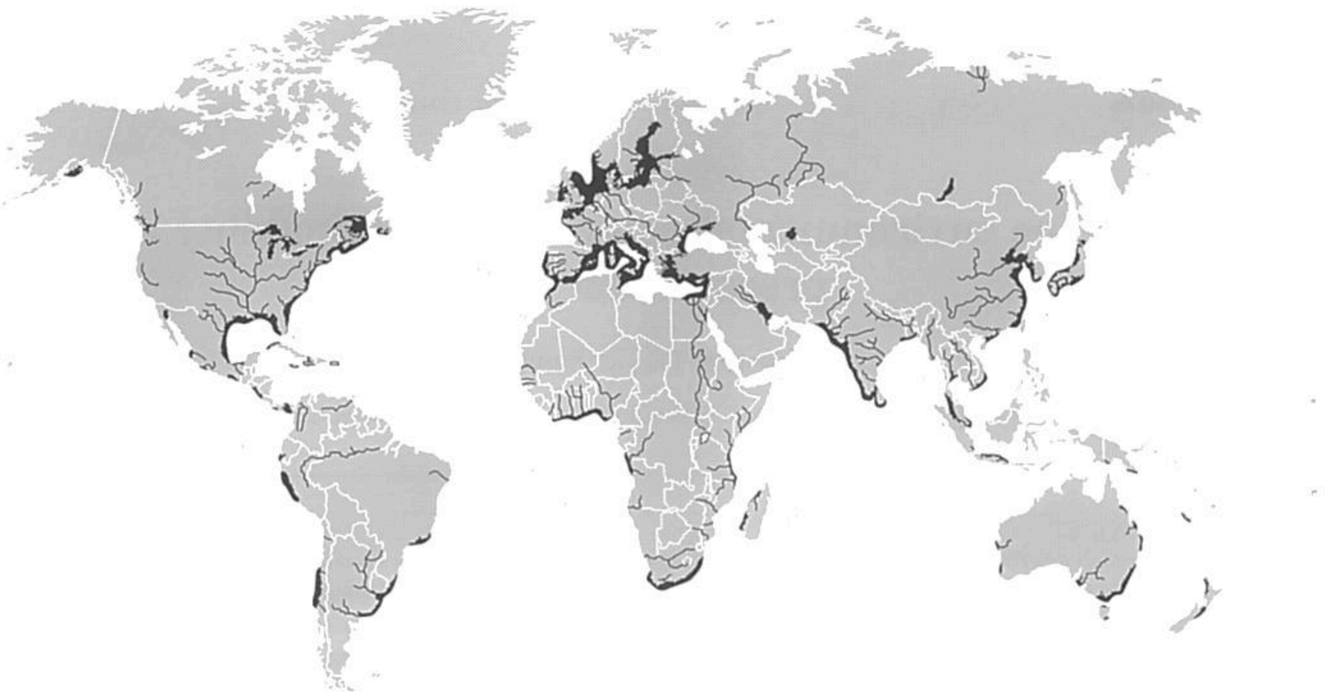

Fig. 1. Outline map of the world showing marine areas at risk from pollution impacts. This does not include possible impacts upon high latitudes from global transport of semi-volatile organic pollutants. *Source*: After Lean and Hinrichsen (1993).

Table 1
The global value of ecosystem services for the year 1994[a]

BIOME	Area (ha × 10^6)	Value ($US ha^{-1} y^{-1})	Total global value ($US × 10^9 y^{-1})
Marine	36 302	577	20 949
Open ocean	33 200	252	8381
Coastal	3102	4052	12 568
Estuaries	180	22 832	4110
Seagrass/algae	200	19 004	3801
Coral reefs	62	6075	375
Shelf	2660	1610	4283
Terrestrial	15 323	804	12 319
Wetlands	330	14 785	4879
Tidal marsh/mangroves	165	9990	1648
Swamps/floodplains	1654	19 580	3231
Forest	4855	969	4706
Tropical	1990	2007	3813
Temperate/boreal	2955	302	894
Grass/rangelands	3898	232	906
Lakes/rivers	200	8498	1700
Desert	1925		
Tundra	743		
Ice/rock	1640		
Cropland	1400	92	128
Urban	332		
Total	51 625		33 268

[a] The global value of ecosystem services calculated for the year 1994. Missing values denote insufficient information to make a calculation. Values were derived on the basis of a limited set of ecosystem services by Costanza et al. (1997). For example, no value is included for the role of oceans in climate regulation. In the context of marine systems, the most highly valued ecological services are provided by coastal ecosystems.

environmental protection. They cannot resolve the overall cost–benefit conundrum associated with the services which ecosystems provide as compared to those lost when they are destroyed. Moreover, such approaches fail at the outset to incorporate consideration of the morals of environmental stewardship and other intangible values.

In looking for a simpler means of assessing the potential and actual significance of human activities, the concept of sustainability, achieved through the preservation of "undamaged" ecosystems and the restoration of degraded ones allows for a more practical, if still qualitative, evaluation of the current problems. The evaluation of sustainability can use as input a wide variety of data drawn from diverse sources to assess conformity with four basic principles. If any one of these principles is violated, then the activity in question is not sustainable. Inevitably, as with other indices of environmental impact, the principles of sustainability are held hostage in some degree to incomplete or uncertain data relating to any proposed or current human activity. Such uncertainties should not be used as an excuse to avoid taking remedial action. Indeed, the uncertainties need to be explicitly accommodated within a suitable paradigm of environmental protection.

The intentions of this paper are therefore twofold. Firstly the concept of ecosystem valuation, and the numerous limitations inherent to such an approach, are discussed in more detail. Secondly the paper applies the principles of sustainability as a yardstick to some of the identified problems based largely upon a previously published extensive review of the problems facing ocean systems (Johnston et al., 1998). It argues that these principles are being demonstrably and comprehensively violated and that in the absence of reliable quantitative indices in the ecological and economic domains, these problems can be best resolved by adopting a stringent precautionary approach to environmental protection.

2. Value and valuation of ocean ecosystems

A major and fundamental concern attached to a purely economic approach to environmental evaluation is the perceived failure to embrace the concept that biodiversity has both a moral and monetary value (Oksanen, 1997). Nevertheless, numerous other serious concerns arise. The support of human existence by the oceans goes far beyond simple exploitation of fisheries and other coastal resources and, as a result, this support cannot be expressed simply in terms of the tangible economic resources taken from it. According to one estimate (Costanza et al., 1997) the coastal and shelf areas account for around 5% of the earth's surface, and the notional valuation attached to these areas (see Table 1) accounts for 60% of the total value of ocean ecosystem services *per annum*. These figures reflect the intensity of current exploitation of these ocean services. The oceans, however, provide humanity with a highly diverse array of what may be termed ecosystem or ecological services. Although in most cases, these ecosystem services accrue directly to humans without passing through formal monetary economies, this does not imply a zero value. The notional fiscal values of the ecosystem services provided by the oceans are impressive. Based on the functions of the open oceans as a regulator of atmospheric composition, nutrient cycling, food production and biological control of natural systems it was estimated that they contribute $8000 billion to the world economy. When coastal waters are included in such estimates, the contribution increases to around $21 000 billion (Costanza et al., 1997), amounting to an estimated 63% of the total value of marine and terrestrial systems combined. These values correspond to around 1.8 times the current Gross World Product (GWP). It must be emphasised that such figures are only indicative. Undoubtedly they underestimate the true contribution. For example, these data do not include any estimate of the fiscal contribution of the oceans to climate regulation, although oceanic processes drive the world's climate and weather systems (Bernes, 1996).

Other highly significant limitations to this approach exist, and were identified as constraints on the process from which the figures in Table 1 arise (Costanza et al., 1997). Ecosystem valuation is a relatively new field and the perceived inherent limitations continue to fuel considerable debate. Values can be assessed on the basis of an individual "willingness to pay" and this is the premise upon which the values in Table 1 were largely derived. The temporal stability and hence the "real world" relevance of the figures is contingent upon two assumptions. Firstly, that individuals live in a manner whereby the marine ecosystem services in question continue to remain fully available, i.e. are not damaged or destroyed by the demands placed on them. Secondly, that individuals recognise the full extent of their connection to, and their dependence upon, marine ecosystems. The first of these pre-conditions is unlikely to be met, to any significant degree, under the currently prevailing lack of constraints, characteristic of market-driven economies (see e.g. Rees, 1998). As to the second assumption, scientific understanding of marine ecosystems and dynamic processes and the overall significance of the oceans is at present very limited, which is a key impediment to the assignment of robust values. Even if these conditions were met, the "willingness to pay" basis of assigning values gives rise to what is termed the "price-value paradox" (Ayres, 1998a). It can be argued that the costs of control, protection and maintenance of ecosystem services (considered as environmental capital) are more practical and realistic indicators of the benefits which accrue from them.

Recognising that limitations exist, some obvious truths concerning assigned fiscal values, derived by whatever means, deserve mentioning. Such values represent an imprecise and subjective estimate of the *benefits* of ecosystem services, generally, to the present generation or a subset thereof (Opschoor, 1998), and cannot be taken as an estimate of the cost of substituting these services by technological means. It is important to note here that in actuality many of these functions are in fact irreplaceable (Cairns and Dickson, 1995). The corollary, in economic terms, is that since the economies of the world would cease to function without certain ecological services, the economic value of those services is infinite (Costanza et al., 1997). The notion, therefore, that environmental damage can be paid for, and that payment is equivalent to, or preferable to, preventing the damage, is seriously misconceived (Beder, 1996).

Further extension of the economic analogy into the case studies outlined later leads to the view that current world development is in fact consuming ecological ''capital'' rather than merely the ''interest'' accruing from sustainable use of ecological services (Cairns, 1996). The impact of many human activities cannot be justified even in terms of benefit over cost – the most minimal interpretation of ecological economics. Put another way, some marine ecological services are being overused even at the currently assigned prices (Costanza et al., 1997). Estimates of the economic cost of this erosion of ecological capital assets, particularly in the long term, suffer from the same limitations as valuation of the assets themselves. The discipline has not yet developed to the point where neutral and robust values are available, which could form the basis of protective policy measures. Available valuation techniques do not yet have the capacity, per se, to provide information which would reduce dependence upon the heuristic environmental protection strategies currently widely used.

Accordingly, using complex econometric techniques to value ecosystem services leads ultimately to one simple conclusion (albeit with highly complex implications), namely that there is a need to shift from a ''growth'' society to a society that comprehensively ''maintains'' assets. Perpetual material growth is not compatible with the continuing availability of ecosystem services (Cairns, 1997a).

3. Principles of sustainability

The principle of preserving the continuing availability of ecosystem services by preserving the full capacity of the ecosystems that provide them is enshrined in the concept of sustainability. This was described as ''the new fundamental issue of the 1990s'' (Ulgiati and Brown, 1998). Attempts to define it have resulted in diverse and sometimes contradictory definitions. This has resulted primarily from the difficulties of integrating diverse conceptual historical roots into one unifying instrument that adequately defines distinct but interrelated issues of environment and human development (Dovers and Handmer, 1993). A central problem seems to be that most definitions are usually only predictions of the sets of conditions that will actually lead to sustainability (Cairns, 1996), rather than definitive criteria. Most definitions, however, embrace the idea that sustainability involves meeting the current societal demand for ecosystem services in a way that ensures that the transgenerational responsibility that these services are not compromised for future generations is met (Cairns, 1997b).

The concept described before can be applied to the qualitative analysis of ocean systems. Such analysis is far simpler than those currently available through ecological economic disciplines, leading to simple yes or no answers which can be integrated in the policy domain. This analysis entails gauging whether current human activities conform to sustainability by assessing their conformity to the following four encompassing principles (Cairns, 1997b):

1. Substances from the earth's crust must not systematically increase in the ecosphere.
2. Substances produced by society must not systematically increase in the ecosphere.
3. The physical basis for productivity and diversity of nature must not be systematically diminished.
4. Resources must be used fairly and efficiently with respect to meeting human needs.

Each of the principles described earlier are required for sustainability and, taken together, are sufficient to ensure that a given activity conforms to the overall paradigm of transgenerational responsibility. In essence, therefore, they can be regarded as first order principles. The principles were extended into a number of specific goals and conditions (see, Cairns, 1997a, b). They also implicitly underpin recently derived principles for sustainable governance of the oceans as detailed by Costanza et al. (1998). As a broad axiom, use of ecosystem services on a sustainable basis cannot violate any one of these principles. It follows that environmental protection should set standards such that there is a very high degree of certainty that these principles will not be compromised. The principles themselves allow some insight into what is or could be happening to a given system and what (precautionary) measures are required to stop unsustainable practices.

Many case studies illustrate problems identified in coastal and continental shelf areas. The following examples and discussions are based upon the premise that unsustainable practices taking place locally and regionally are having discernible impacts upon the wider oceanic domain or constitute, in aggregate, a global trend compromising ecosystem services on a global scale.

4. Land based activities: pollution

Land based activities are estimated to contribute some 77% of pollutants entering the marine environment by direct and indirect means with shipping (12%), sea dumping (10%) and offshore oil industry (1%) making up the balance. Virtually all industrial activity has the potential to emit polluting substances, and the array of chemicals involved is extremely wide.

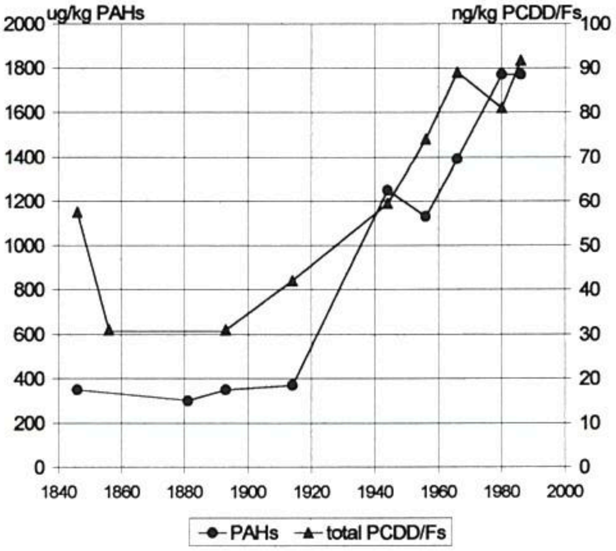

Fig. 2. Increase with time of total chlorinated dioxins and dibenzofurans (PCDDs/Fs) and PAHs in an archived series of agricultural soils from the UK. The influence of the expanding industrial base and dependence upon fossil fuels is clearly visible. *Source*: Kjeller et al. (1991) and Jones et al. (1989).

In the case of emissions from mining and metal processing, deleterious impacts were recognised and recorded from classical Greek times through the middle ages to the modern era (Nriagu, 1992). By the middle of the 17th century, metals released from smelting processes in the UK and central Europe were causing elevations of metal levels in remote regions of Scandinavia. Metal fluxes from human activities now equal or exceed inputs from natural sources in many cases. Estimates of metals reaching the ocean from the atmosphere, the primary transport and distribution medium, show a strong regional variation. Ocean waters closest to the regions of most intense industrial activity, unsurprisingly, receive the greatest inputs (Nriagu, 1990; 1992). Various data indicate that metals were systematically accumulating in the ecosphere. Emissions of some metals are estimated to have trebled or quadrupled between 1900 and 1990, and this is detectable even in remote areas. An example is provided by coral skeletons in the Pacific: those recently deposited contain 15 times more lead than those laid down 100 years ago. Increases in metal content seems to be a continuing trend. Metals are central to current global economies and improved controls upon emissions in industrialised countries are likely to be offset by increased emissions elsewhere as industrial development expands in developing regions such as the African continent (Biney et al., 1994).

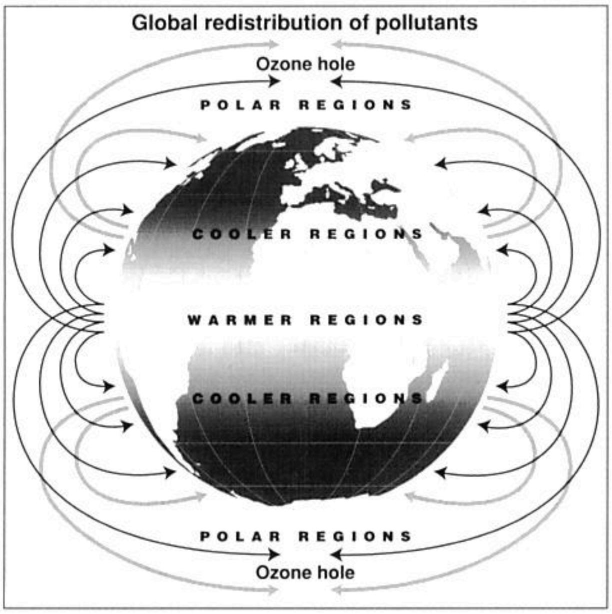

Fig. 3. Diagrammatic representation of global atmospheric circulation patterns in the transport of persistent organic pollutants to high latitudes by means of a global condensation mechanism. Chemicals rendered volatile in areas with high ambient temperatures are transported to cooler regions where they condense. *Source*: After Wania and Mackay (1993).

Various impacts upon natural ecosystems were described in the literature, usually as the result of the study of specific point sources (see, Johnston et al., 1998). The significance of the progressive increases in environmental metal levels to human populations can be gauged from estimates that currently up to half a million humans may be suffering from kidney disorders as a result of cadmium exposure, that between 40 000 and 80 000 people may be suffering the toxic effects of mercury owing to consumption of contaminated seafood. In the case of lead it is estimated that anywhere up to 200 million are at risk of poisoning (Nriagu, 1988). This situation has evolved through market economies predicated upon stimulated demand, changing fashion and built in obsolescence, coupled with a complete reliance upon fossil fuels which themselves release metals to the environment.

Synthetic chemicals derived from the combustion and chemical processing of petroleum began to increase in the environment with the advent of widespread industrialisation. This is indicated by the data shown in Fig. 2 for two chemical groups analysed in UK agricultural soils. A key development was the emergence of a chemicals market based upon chlorine chemistry. This led to a range of synthesised chemicals being introduced from the 1920s onward. The diversity of such chemicals, market development and penetration increased rapidly in subsequent decades.

Some 63 000 chemicals are estimated to be in common use worldwide with anywhere between 200 and 1000 new synthetic materials entering the market each year (Shane, 1994). Around 3000 chemicals comprise 90% of the production. For many chemicals discharged, their toxicological data are sparse or lacking, and for many others the toxicological information cannot be reliably identified. A full evaluation is therefore not possible (Johnston and Stringer, 1991).

Table 2
The production and use of synthetic chemicals[a]

Compound	Date production started	Cumulative world production/use (tonnes)	Current use (tonnes)
DDT	1942	2.8–3 million	50 000
Chlordane	1947	70 000	200
Heptachlor	1952	No data	No data
Toxaphene	1948	1.33 million	None known
Technical HCH	1942	550 000	Not known
Lindane	1942	720 000	10 000
Aldrin/Dieldrin	1950	240 000	None known
Mirex	1959	Not known	None known
Hexachlorobenzene	1945	Highly uncertain	200 000
PCBs	1929	1–2 million tonnes	None known

[a] Historical and current estimates of production of organochlorine pesticides and chemicals. All figures are subject to wide confidence limits since no production figures are known in many cases for former Eastern Bloc countries. *Sources*: Voldner and Li (1995); IEM (1995); Smith (1991); Tanabe (1988).

As with emitted metals, the footprints of the organic chemicals industry can be found around the globe. Residues of chlorinated pesticides and other organic chemicals can be traced in the tissues of marine organisms originating from all parts of the world. Recent evidence of the global transport of these chemicals suggests that chemicals emitted in temperate and tropical regions are being transported through the atmosphere towards colder regions of the globe (Wania and Mackay, 1996). Here, they ''condense'' out into the surroundings and contaminate regions remote from industrial areas, degrading the food resources upon which indigenous communities depend (see Fig. 3). The production and use of some of the most widely used synthetic chemicals is shown in Table 2. In addition, unwanted by-products from the processes of manufacture, use and disposal of chlorinated chemicals, such as the chlorinated dioxins and dibenzofurans, behave in a similar manner to other chorinated chemicals of concern.

Table 3
Estimates of radioactivity in the oceans[a]

Source	Quantity
Cosmogenic/terrestrial (natural)	$1.6–2.0 \times 10^7$ PBq
Atmospheric testing	$1.5–2.0 \times 10^5$ PBq
Fuel processing[b]	4.8 PBq
Fuel reprocessing	Not known
Sellafield (1992) (Excl. Tritium)	76 TBq
After THORP commissioning (Excl. Tritium)	520 TBq
Tritium discharged (1992)	3500 TBq
Accidential releases/debris	Total unknown
Windscale, UK (1957)	768 TBq
Idaho Falls, USA (1961)	4 TBq
Three Mile Island, USA (1979)	1×10^2 PBq
Chernobyl, USSR (1986)	1.85×10^3 PBq
Disposal/dumping (total)	$> 1.5 \times 10^2$ PBq
North Atlantic dumpsites (26)	45 PBq
Pacific dumpsites (21)	0.57 PBq
Arctic dumpsites (USSR) (> 20)	90 PBq

[a] Cumulative inputs of natural and artificial radionuclides into the oceans by source. 1 PBq = 1 Bq $\times 10^{15}$, TBq = 1 Bq $\times 10^{12}$. Releases from Three Mile Island largely radioactive noble gases with short half life. Numbers of dumpsites shown in parentheses. Information from Broadus and Vartanov (1994) and Hewitt (1990).

[b] The figure given for fuel processing does not appear to include emissions from fuel reprocessing. Illustrative figures for Sellafield for 1992 and after the new THORP plant is commissioned (OSPAR, 1992; NRBP, 1993) are given exclusive of values for tritium. Tritium figures for 1992 are given in parentheses.

Radioactive elements are also systematically increasing in the ecosphere as a result of military and industrial nuclear testing and other activities although the radioactive inventory in the oceans is dominated by natural radionuclides. As with synthetic chemicals, however, many artificial radionuclides have no natural counterparts and have extremely long environmental lifetimes. Table 3 shows estimates of the cumulative input of radioactivity into the oceans, including materials dumped illegally into the Arctic Ocean. Facilities in the UK and France are currently the most important point sources of radioactivity in the oceans. Radioactivity emitted from these sources is transported in ocean currents and can be traced in remote arctic regions (MAFF, 1991). Other radionuclides have become localised in the sediments close to the plants, acting as an unpredictable source of particularly long-lived isotopes into adjacent ecosystems (Kershaw et al., 1992). The nuclear industry continues to emit artificial radionuclides. In addition, certain mineral processing industries emit substantial quantities of natural radioactive elements.

What emerges from this necessarily brief overview is evidence of a clear and continuing violation of the first two principles of sustainability. Natural and synthetic materials continue to increase systematically in the ecosphere, and on this basis, the current global chemical economy is clearly operating on an unsustainable basis. In coming to this conclusion, based upon the principles of sustainability, it has not been necessary to demonstrate ecosystem degradation resulting from these inputs. By considering chemical

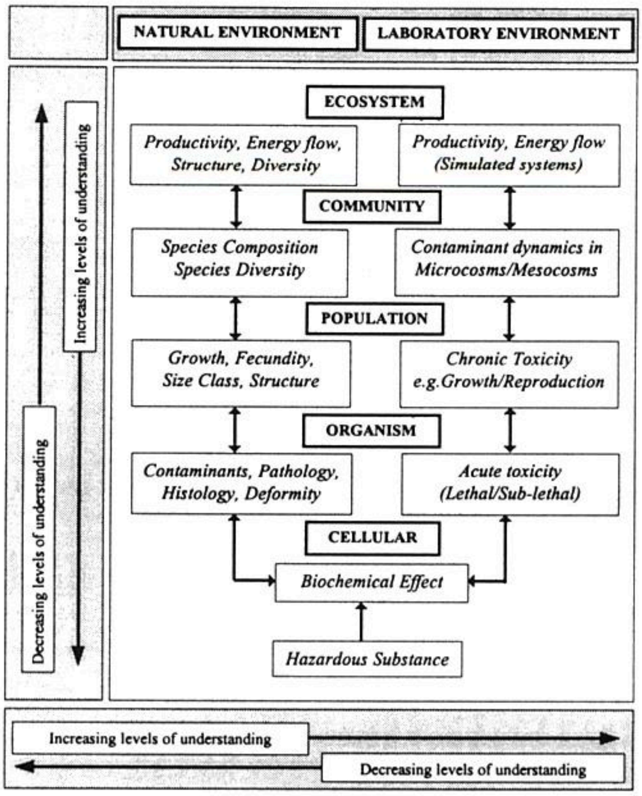

Fig. 4. The relevance of toxicological data to protection of biological systems at different levels of biological organisation. Toxicological endpoints in natural and artificial systems are shown. Generally, levels of understanding decrease for natural systems and with increasing levels of organisation. Hence, the relevance of single species toxicity tests to whole ecosystem protection is highly questionable. *Source*: Santillo et al. (in press).

releases leading to chemical build-up in the environment undesirable per se, the sustainability principles hint at a management strategy that does not depend on the identification of causal toxicological interactions in natural ecosystems. This is significant given the large numbers of uncertainties and indeterminacies that characterise current understanding of ecosystem processes. This is illustrated in Fig. 4, which shows the relatively low applicability of toxicological data derived from single organism testing to the prediction of effects at the ecosystem level (see, Santillo et al., in press).

The importance of the independence of the principles of sustainability from absolute demonstration of causal effect is illustrated by the growing appreciation that many chemicals entering the environment have the capacity to interfere with hormone metabolism. Hormones control many developmental and reproductive processes (Colborn, 1994) and agents which interfere with these systems have the potential to undermine the stability of whole populations and ecosystems. Even though this new potential toxicological mechanism was identified, the detection of impacts on ecosystems is likely to prove extremely difficult. Impacts are likely to be very subtle, and no reliable means as yet exists for their detection. Nevertheless, it must be recognised that the prospect of transgenerational impacts is a very real one given the long persistence of many of the chemicals of concern once released to the environment. Their tendency to concentrate in body fat allows them to be passed to mammalian offspring in the fat of maternal milk, again raising the possibility of transgenerational effects. Although substantial uncertainties remain, the potential for violation of the third principle of sustainability must, therefore, be taken into account.

5. Marine capture fisheries

Marine fishing is a highly significant human activity generating around 1% of the visible global economy and supporting the livelihoods of some 200 million people. The effect of intensive fishing on marine ecosystems is discussed at greater length by McGinn (this issue). Insofar as these impacts diminish the production of fish as food and limit the biological, and hence economic, productivity of ecosystems, they clearly violate the third principle of sustainability. By focusing only upon single species populations, relatively little attention was directed at impacts upon the wider ecosystem of which they are a part. By the early 1980s however, it had become clear that replacement of longer-living fish species by smaller shorter-lived species had taken place in the Gulf of Thailand, the North Sea and off the west coast of Africa (Garcia and Newton, 1994). Ecosystems at the intensively fished Georges Banks, where cod populations collapsed owing to overexploitation, have shown a trend towards an increase in fish of low commercial value, specifically shark and ray species (Fogarty and Murawski, 1998).

The most compelling evidence of the potential for a general, global ecological regime shift has come with a recent re-analysis of FAO catch statistics (Pauly et al., 1998). This has shown that progressive fishing down food chains has occurred as fishing effort responds to depletion in the original target stocks. A consistent downward trend in the trophic level occupied by commercially fished species was identified in global fisheries as the predatory demersal fish are superseded as targets by pelagic fish which feed lower in the food chain. The significance of these actual and potential regime shifts is subject to debate. The view that these changes result in an ecologically acceptable, though economically less valuable, fish community (Steele, 1998) ignores transgenerational responsibilities and also contrasts with the view that regime shifts may result in the establishment of a stable but undesirable ecosystem.

In addition to the pressure of overfishing, physical disturbances by fishing gear also impact upon ecosystems. It was estimated that in 1985, trawls and dredges swept tracks of 4.3 million km in length across the Canadian continental shelf. Some areas of the southern North Sea are swept by beam trawls up to seven times a year (Johnston et al., 1998) causing extensive damage to benthic ecosystems. Bycatch includes not only fish species but species of turtles, seabirds, and cetaceans, some of which are nearing extinction owing to these activities.

One common historical response to the crisis in world fisheries was to impose quotas on fish stocks. Most recently, individual transferable quotas (ITQs) were favoured as a management instrument. In New Zealand and Iceland, where these instruments were applied over a number of years, the evidence of benefit to the fish stocks was equivocal at best. What is clear, however is that these instruments have concentrated the rights for exploitation of fish stocks into the hands of considerably fewer individuals, often large scale industrial concerns. This then raises the question of whether the fourth principle of sustainability is being violated as a result of these trends. Uncertainties in the models used, poor knowledge of multi-species impacts, the use of inappropriate management targets, (exemplified by the use of the concept of minimum biologically acceptable level (MBAL) in the North Sea), fishing fleet overcapacity, and misguided government subsidisation of the industry have jointly contributed to the current crisis in marine fisheries. Increasingly, fisheries scientists are calling for fundamental changes to the current management paradigm which is seen as fatally flawed, a subject elaborated in detail by McGinn (this issue). It is thought that, while there is some evidence that some fish populations will be unable to rebuild from low stock levels, the effects of overfishing should, in theory, be reversible at the present stage. The key to achieving this and meeting transgenerational responsibilities is rigorous and protective management of marine resources.

6. Climatic change

The responsibilities of the current generation to those of the future are clearly exemplified by the potential impacts of climatic change upon marine ecosystems. Current use of fossil fuels releases large quantities of carbon dioxide to the atmosphere. This, together with other gases and industrial chemicals released to the atmosphere, acts as a ''greenhouse gas'', trapping proportionately more of the heat radiated from the earth's surface, although still allowing solar radiation to heat the surface. This net increased retention of heat in the atmosphere is projected to raise global average surface air temperatures by between 1°C and 3.5°C by the year 2010, relative to temperatures in the year 1900. Increasingly, it is acknowledged that human activities have had a discernible impact upon global temperatures over the last 50 years (DETR, 1998; IPCC, 1996a).

Estimates of the precise rise in temperature likely to result vary, but appear to be greater than any historical changes since the ending of the last ice age 10 000 years ago. The precise impacts of a global temperature rise are extremely hard to predict due to the intricate interconnections between the various parameters governing global climate. This point is made by Mason and Ragland (this issue). Nonetheless, as they also point out, increases in sea level and in ocean temperature regimes could have a profound effect upon ecological systems. Potential impacts reported in the literature include the inundation of low lying areas, changes in ocean productivity and circulation patterns (IPCC, 1996b; Rahmstorf et al., 1996; DETR, 1998), ecosystem structure and organismal distribution (Reid, 1989; IPCC, 1996b). That the potential for far reaching changes is more than fantastic speculation is illustrated convincingly by the profound climatic changes resulting from the natural phenomenon known as the El-Nino-Southern Oscillation. The extensive changes in global climate and weather resulting from this natural shift in ocean and atmospheric circulation patterns are discussed in detail by Mason and Ragland (this issue).

In the sense that the globe is committed to a temperature rise in the future as a result of human activity, specifically fossil fuel use, intergenerational responsibilities were already abdicated to a significant degree. In allowing the build-up carbon dioxide in the atmosphere, arguably both a societal product and a component of the earth's crust, the first and second principles of sustainability were breached. The subsequent temperature rise threatens to cause numerous violations of principles three and four. The question at present is not one of how climate change can be prevented but rather one of keeping the impacts within certain limits in order to allow marine systems to accommodate the predicted changes and to preserve their functioning to the maximum extent possible (see discussion of the precautionary approach later). This will also require considerable discipline in the exploitation of marine resources to ensure that the pressures of climate change added to other existing pressures do not fatally compromise them.

7. A precautionary approach to environmental protection

The foregoing examples serve to illustrate how comprehensively human activities in relation to the ocean are in breach of the principles of sustainability. As noted before, adequate environmental protection requires a very high probability that principles of sustainability will not be violated. In turn, this can be more readily ensured by a precautionary model of environmental protection. Indeed, it can be argued that implementation of precautionary policies is the most realistic approach to ensuring that environmental degradation is halted and reversed, leading to wide scale restoration of ecosystems.

The precautionary approach to environmental protection emerged originally from efforts to regulate and control hazardous chemicals entering the sea (Jackson and Taylor, 1992), as exemplified by its adoption at the 1987 Ministerial Conference on the North Sea (MINDEC, 1987). Subsequently it was affirmed as a general protective axiom in Principle 15 and Agenda 21 of the 1992 Rio Conference on Environment and Development. Other agreements specifying such an approach include the UN Agreement on the Conservation and Management of Straddling and Highly Migratory Fish Stocks (1995), The Paris Convention (1992) the 1996 Protocol to the London Convention and the Barcelona Convention as amended in 1995. Broadly speaking, a precautionary approach recognises scientific and technical limitations and promotes regulatory action in the absence of full evidence of a cause–effect relationship. In short, it allows incomplete data, uncertainty and indeterminacy to be taken into account in a meaningful way in the decision-making process.

A precautionary approach to environmental protection can be defined as:

> The emplacement of appropriate preventative measures when there is reason to believe that harm is likely to be caused by anthropogenic activities including the introduction of substances or energy into the environment and the extraction of marine species (including non-target species). Action should be taken even where there is not conclusive evidence to prove a causal relationship between the actions and their effects.

This contrasts with measures taken only after harm was identified and allows consideration of all the information available. It effectively reverses the burden of proof and places it upon those seeking to exploit ocean resources at the potential expense of ecological services. In relation to the broad principles of sustainability, if it cannot be proven that a given activity is not going to violate one or more of these principles, then a new activity should be prohibited. An existing activity which is shown to be in violation should be stopped or modified in such a way as to become sustainable. Tighter control may be appropriate only if an existing activity is not breaching the first or second principles. Hence, a precautionary approach to environmental protection can be regarded as an instrument of both pragmatic regulatory activity and of sustainability.

Precaution has most recently emerged as a key principle among recently proposed principles for sustainable governance of the oceans (Costanza et al., 1997). Only ten years or so ago precaution was a concept which, like sustainability (Cairns, 1998), was regarded as somewhat extreme. A hardcore resistance to the concept still exists (Santillo et al., in press) but there is no doubt that both concepts have entered mainstream regulatory and policy arenas.

8. Application and implementation of a precautionary approach

A precautionary approach to the regulation of chemicals is the easiest to visualise. The idea of zero-emissions was regarded as hopelessly idealistic and extreme ten years ago. Like the precautionary approach itself, it too has now entered the mainstream. The 1995 North Sea Ministerial Declaration (MINDEC, 1995) holds a commitment to eliminate discharges of hazardous chemicals within one generation (i.e., by 2020). This was taken up by the signatories to the 1992 Paris Convention in the 1998 Sintra Statement. The economic aspects of a zero emission economy were also explored, and these suggest that economic systems will need to undergo a profound shift if the goal is to be attained (Ayres, 1998b).

Fisheries management under a precautionary paradigm also implies far reaching changes in the industry. A first priority is reduction of the global capacity of large scale industrial fleets by something on the order of 50%, strengthening regional efforts to cut capacity and remove subsidies. Parallel efforts should be directed at restricting fishing and concomitant impacts upon marine populations such that the character of the ecosystem is not changed by fishing, taking into account by-catch and habitat disturbance as well as the target stocks. Restoration of depleted stocks is a key element of this approach. Fisheries should not be allowed to operate in the absence of data on target populations, and catches should be set low to reflect poor data quality. All fishery activity should be underpinned by a well-planned response strategy if limits are exceeded or unanticipated events take place. The establishment of marine reserves is a potentially useful strategy in contributing to the restoration of depleted stocks and damaged ecosystems under a precautionary paradigm (Lauck et al., 1998). To date, schemes designed to introduce precaution into fisheries management (Caddy, 1995) indicate that, in fisheries, precaution as a concept lags behind compared to the application of the concept in chemicals regulation. Management schemes will need to evolve rapidly to protect against possible regime shifts in the short to medium term and to place fisheries on an ultimately sustainable footing.

A precautionary approach to protection from climatic change, without doubt, will require the most fundamental overhaul of industrial and economic systems. Such is the magnitude of the potential problem that failure to respond adequately may well render most other environmental protection strategies superfluous. As with other issues, strategies will need to accommodate the inherited, historical aspects of the problem. While restoration may be possible for chemically damaged or over exploited marine systems, in the case of climatic change the issue is more of damage limitation. This implies strict limits on the use of fossil fuels to keep predicted changes within limits which most ecosystems are likely to be able to tolerate. It was estimated (Hare, 1997) that ''manageable'' levels of change will constrain fossil fuel use to around 225 billion tonnes of carbon in total, or around 25% of current reserves. Current emissions are around 7.1 billion tonnes of carbon annually, hence this implies that there are 30 years in which to achieve a rapid transition away from fossil fuels into renewable energy resources. Even so, this does not guarantee that temperatures will not exceed the tolerable limit of 1°C rise or that sea level rise will be restricted to 20 mm per decade for a final stabilisation level of 20 cm above the 1990 levels. It is thought that adhering to these targets will allow the vast majority of vulnerable ecosystems to adapt (Rijsberman and Swart, 1990). Nonetheless, they do not guarantee that catastrophic changes will not occur. The 225 billion tonne ceiling simply makes them less likely.

What is illustrated by these issues in relation to the definition of a precautionary approach is that precaution works best when applied prospectively to the protection of marine systems through its direct application to prevent unsustainable activities. Nonetheless, while prevention is certainly better than cure, precaution also has a significant role to play in the restoration of damaged ecosystems and in restricting the scale of any damage likely to occur while unsustainable human activities are brought progressively onto a sustainable footing. Indeed under these circumstances, precaution is the best means available of ensuring that the regulatory scenario does not simply encourage ''business as usual''.

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