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Marine Biodiversity:
patterns, threats and conservation needs

by

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PREPARATION OF THIS STUDY

In 1995 GESAMP was asked by its sponsoring agencies to prepare a study identifying threats to marine biodiversity and their consequences. GESAMP agreed that an appropriate starting point towards achieving such an aim would be to prepare the outline of a review setting out the main issues of marine biodiversity, to analyse the threats to diversity and to suggest a strategic outline or framework identifying actions which would ensure conservation of marine biodiversity.

Prof. John S. Gray, a member of GESAMP, prepared the review which was approved by the Group at its twenty-sixth session in 1996 for publication in the GESAMP Reports and Studies series.

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ABSTRACT

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection)

Marine Biodiversity: patterns, threats and conservation needs.

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Marine biodiversity is higher in benthic rather than pelagic systems, and in coasts rather than the open ocean since there is a greater range of habitats near the coast. The highest species diversity occurs in the Indonesian archipelago and decreases radially from here. The terrestrial pattern of increasing diversity from poles to tropics occurs from the Arctic to the tropics but does not seem to occur in the southern hemisphere where diversity is high at high latitudes. Losses of marine diversity are highest in coastal areas largely as a result of conflicting uses of coastal habitats. The best way to conserve marine diversity is to conserve habitat and landscape diversity in the coastal area. Marine protected areas are only a part of the conservation strategy needed. It is suggested that a framework for coastal conservation is integrated coastal area management where one of the primary goals is sustainable use of coastal biodiversity.

Keywords: patterns of diversity; threats; habitat and landscape conservation; integrated coastal area management.

1 INTRODUCTION

Although there are a number of general reviews of biodiversity, such as the Global Biodiversity Assessment (Heywood and Watson, 1995) and Huston's (1994) more theoretical approach, there is no concise synthesis of marine biodiversity in relation to conservation needs. Short general reviews cover coastal-zone biodiversity patterns, (Ray 1991), deep sea benthic diversity, (Grassle 1991), marine benthic biodiversity research, (Lambshead 1993), marine functional diversity (Steele 1991), coral reefs (Jackson 1991), foraminifera, (Buzas 1991), fish diversity in the Caribbean (Robbins 1991) and whale and dolphin diversity (Perrin 1991).

Angel (1993) reviews possible causes for the patterns of the pelagic biodiversity in the ocean and Suchanek (1994) temperate coastal marine biodiversity showing that temperate systems are among the most productive and diverse. Coral reefs, with their associated flora and fauna, although highly diverse, are still relatively poorly described and their functioning is not well understood (Sebens 1994). However, not all coral reefs are highly diverse, inshore shallow habitats on the Pacific rim have physically tolerant species to elevated temperatures and surface irradiance (B.E. Brown pers, comm.) and are threatened by exploitation, dredging and removal. Such low diversity areas are also in need of conservation. Rao (1991) has reviewed the threats to mangroves and states the objectives for their conservation as: maintenance of genetic resources, sustainable utilisation and conservation or re-creation of suitable habitats.

The research agenda for biodiversity has been fully expounded by Solbrig (1991) and Grassle et al. (1991) and more recently for marine biodiversity by the US National Research Council, (1995). These set out priority research problems yet do not deal with conservation aspects of marine biodiversity. The purpose of this paper is to give a concise review of marine biodiversity explaining why it is different from terrestrial and freshwater diversity, analyse the threats and suggest conservation needs.

2 WHAT IS BIODIVERSITY?

At the United Nations Conference on Environment and Development in Rio in 1992 the Convention on Biological Diversity was concluded. Subsequently it has been signed by the requisite number of nations and has now come into effect. In the Convention **biological diversity** is defined as:

> "The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species and of ecosystems."

Biological diversity is often written in shorthand as biodiversity and here the two terms are taken as being synonymous.

2.1 Genetic diversity

The most basic level of biological diversity is that found within a species and is known as **genetic diversity.** Genetic diversity encompasses the variation among individuals within a population in their genetic make-up and the genetic variation among populations. Each species consists of one or more populations of individuals. A population is usually defined as a group of individuals that can interbreed and, if sexually reproducing, can interchange genetic material. Different populations tend to diverge genetically due to their having limited genetic mixing or mutations, natural selection, genetic drift and the accumulation of selectively neutral mutations. Thus there are genetic differences both among individuals and among populations. Populations with higher genetic diversity are more likely to have some individuals that can withstand environmental change and thereby pass on their genes to the next generation (Nevo et al.1987). On an evolutionary time scale (over many generations), genetic diversity is higher in species which characterise unstable, stressed environments when compared with deep sea species. Nevertheless even this lower figure would be a substantial increase in the approximate figure of 300,000 known marine species.

Over geological time there has been a large change in the ratios of orders to families to genera to species. A rapid increase occurred in higher taxa (orders and families) until the Ordovician when diversity levelled off. In the Permian, some 50% of marine families became extinct (Raup 1979, Sepkoski 1979, Sepkoski 1984, Sepkoski 1991). The number of species has increased enormously in recent geological time, more than doubling compared with those present 100 million years ago (Signor 1994).

Most marine species diversity is benthic rather than pelagic (Angel 1993). This is a consequence of the fact that the marine fauna originated in benthic sediments. The pelagic realm has an enormous volume compared with the inhabitable part of the benthic realm. Yet there are only 3,500-4,500 species of phytoplankton (Soumia & Chretiennot-Dinet 1991) compared with the 250,000 species of flowering plants on land. Angel estimates that there are probably only 1,200 oceanic fish species against 13,000 coastal species. In the pelagic realm, diversity is higher in coastal rather than oceanic areas (Angel 1993) and therefore, efforts should be concentrated in coastal areas.

Another highly important aspect of species diversity is endemism, (that is the species occur in a restricted locality). The Antarctic has a higher degree of endemism than the Arctic. In the Red Sea 90% of some groups of fishes are endemic. Overall however, only 17% of Red Sea fishes are endemic (Sheppard 1994). In a survey of 799 pan-tropical fish species Roberts et al. (in Sheppard 1994) showed that 17% occupied only one grid square (223 x 223 km). In the Indian Ocean of the 482 coral species recorded 27% occur only at one site (Sheppard, 1994) and of the 1,200 species of echinoderms at 16 sites, 47% occurred at only one site (Clark & Rowe 1971). High degrees of endemicity pose particularly severe problems for development of conservation strategies. Questions that need to be raised are: Are all species equally important for conservation purposes? Do some endemic species play more significant roles than others in the structuring or functioning of the habitat concerned?

The urgency of the need for assessments of species diversity has led to the development of a number of new "rapid assessment" techniques. Non-specialists have been trained in a few days to sort samples into taxonomic groups with a high degree of precision (Oliver & Beattie, 1993). Whilst the identification of the actual species must be done later by specialists these techniques allow rapid assessment of the species diversity of areas that have not been fully studied. These methods need to be further tested in tropical marine areas but show great promise.

2.3 Phyletic diversity

In the marine domain there are more animal phyla than on land. Thirty five phyla are marine and of these 14 are endemic whereas only fourteen occur in freshwater, where none are endemic eleven are terrestrial with one phylum being endemic and 15 phyla are symbiotic with 4 being endemic, (Briggs, 1994; Ray & Grassle, 1991). This figure includes the newly described phylum Cycliophora found in the gills of the Norway lobster (Funch & Kristensen, 1995). Thus **phyletic diversity** is highest in the sea. Of the 35 marine phyla only 11 are represented in the pelagic realm (Angel 1993), most phyla occur in the benthos which is the archetypal habitat. Despite the fact that there are some rare phyla containing only a few species, it is extremely unlikely that present environmental threats will lead to reduction of phyletic diversity.

2.4 Functional diversity

Functional diversity is the range of functions that are performed by organisms in a system. The species within a habitat or community can be divided into different functional types such as feeding guilds or plant growth forms or into functionally similar taxa such as suspension feeders or deposit feeders. Functionally similar species may be from quite different taxonomic entities.

contain are termed habitats. **Habitat diversity** is a more useful term than that of ecosystem diversity since habitats are easy to envisage (e.g. a mangrove forest, a coral reef, an estuary). Furthermore, habitats often have clear boundaries. Habitats have been termed "the template for ecology" (Southwood 1977).

There are strong relationships between sampling scale and the processes that influence diversity (Huston, 1994). At small scales all species are presumed to interact with each other and to be competing for similar limiting resources. Ecologists have called this **within-habitat** (or alpha) **diversity** (Fisher et al 1943; Whittaker, 1960, 1967). At slightly larger scales habitat and/or community boundaries are crossed and sampling covers more than one habitat or community. This scale has been called **between-habitat** (or beta) **diversity** (Whittaker, 1960, 1975, 1976). At an even larger scale (regional scale) where evolutionary rather than ecological processes operate, the pattern has been called gamma diversity or more recently landscape diversity (Whittaker 1960; Cody 1986). **Landscape diversity** can be defined as the mosaic of habitats over larger scales often hundreds of km. Franklin (1993) discusses landscape diversity in relation to biodiversity conservation. (Ray 1991) calls the marine equivalents seascapes). Much attention has been given to ways of conserving landscape diversity on land. Clearly a given habitat can be maintained but landscape diversity can be reduced if the mosaic of habitats is altered. It is clearly important, therefore, to specify what scale (and hence type of diversity) is being studied.

In an important recent paper Tuomisto et al (1995) have shown from an analysis of satellite images followed by extensive ground truthing that beta diversity has been greatly underestimated in tropical rain forests. Since the between-habitat (beta) diversity has been underestimated then the landscape diversity will also be underestimated. The authors point out that the conservation value of different areas depends on a sound estimate of between-habitat and landscape diversity. This is a topic that will need thorough consideration and discussion in any future conservation strategy.

Within coastal areas there are a wide variety of habitats with known high species diversity such as sea grass beds (McRoy 1981), coastal sedimentary habitats (Gray 1994), mangal (MacNae 1968), (Walsh 1974) and coral reefs (Loya 1972), (Huston 1985), (Sheppard 1980). Ray & Gregg (1991) have analysed the coastal wetland areas of Virginia and the Carolinas, USA and conclude that there are large differences in the proportions of salt and freshwater marshes, forest/scrub-shrub and tidal flat areas which lead to differences in biodiversity between the two areas. Ray classifies marine habitats into 20 categories as a basis for characterising coastal areas, (Ray 1991). Coral reefs are themselves highly variable with large differences between the reef flat, reef crest and reef slope both in coral and associated species and each component is probably best considered as between-habitat diversity. Hard rocky surfaces have a rich encrusting flora and fauna, for example in clumps of mussels. Suchanek (1992) found over 300 species in Washington, USA, and within kelp holdfasts (*Laminaria digitata*) in boreal areas Moore (1973) found over 350 species on the species poor East coast of UK.

Yet it is not only the high diversity areas that are in need of conservation. It is often in low diversity areas that productivity is highest and humans exploit these systems (e.g. upwelling areas and estuaries) for food resources and other uses. Estuaries with low species numbers due to salinity stress are habitats that are under severe threats from urbanisation and industrialisation. Arctic marine systems have relatively low diversity and there are low diversity coral habitats that are subject to a variety of threats. Thus one cannot set priorities for marine diversity conservation based simply on habitats with high diversity.

Ray (1991) argues cogently that biodiversity assessments need to be made at the community, habitat and landscape levels if we are to predict changes over time. In a review (by WWF, IUCN and UNEP) of ways of conserving genetic diversity of freshwater fish it was recommended that the best way to conserve species diversity is to conserve habitats (Nyman 1991). Ogden (1988) and Ray & Ray (1992) give examples showing species that use a coral reef during the day and migrate to seagrass beds or mangroves at night. Often sea grass beds are an integral part of the coral reef system. Thus it is the time, which have given rise to allopatric speciation, (speciation caused by the erection of physical boundaries between populations) followed by periods of reunification which has given sympatric speciation (speciation within a population, usually caused by competitive interactions). Throughout geological time there have been massive extinctions followed by rapid evolution and speciation (Kauffman and Fagerstrom in Huston 1994).

3.3 Other marine biodiversity patterns

Another pattern that has received much attention is that in soft sediments with increasing diversity from shallow areas to the deep sea (Sanders 1968). This has recently been confirmed by Grassle & Maciolek (1993) in a study along a transect of 176 km off the US East coast at depths of between 1500m and 2100m. A total of 798 species was found among 90,677 individuals from an area sampled of $21m^2$.

It has been assumed that the data presented by Sanders are representative of a general pattern of low species diversity in shallow coastal areas. Surprisingly no-one has questioned whether or not this is the case. This is all the more remarkable since there are very large numbers of studies done in coastal areas. Using data obtained from the Norwegian continental shelf in the North Sea, Gray (1994) found over a distance of 1200 km a total of 620 species from 39,582 individuals. These data together with those of Poore and Wilson (1993) raise the question of whether coastal biodiversity shows values as high as that of the deep sea. More quantitative information from coastal areas is needed particularly from tropical coasts and from the southern hemisphere.

4 THREATS TO MARINE BIODIVERSITY

With the exception of ocean dumping and UV-B radiation there are probably few human activities posing major threats to oceanic diversity. However, long-transported materials enter the open ocean system and there are concerns about effects of organochlorine compounds on planktonic and benthic systems. The oceanic system is open and continuous and it is unlikely that contaminants will lead to measurable effects on diversity, such as local or regional extinctions. Organisms that live near tectonically active zones where plates are diverging have high diversity and naturally high levels of heavy metals and derive their primary energy from chemosynthesis rather than from sedimenting products of photosynthesis.

Most of the threats to biodiversity are in the coastal zone and are a direct result of human population and demographic trends. The world population has more than doubled since World War II and is expected to increase from 5.5 billion in 1992 to 8.5 billion by 2025 (UN Population Bureau, Anon.1993). More important however, are the demographic trends of increased population densities in coastal areas. It is estimated that 67% of the global population lives on the coast or within 60 km of the coast and the percentage is increasing (Hammond 1992). Within 30 years this population will double, (Norse 1994). Furthermore, many of the largest cities in the world, where population growth rates are highest, are near the coast (e.g. Sao Paulo, Shanghai, Hong Kong, Manila, Djakarta). These burgeoning populations increase pressures on utilisation of resources in coastal areas and in addition lead to habitat degradation, fragmentation and destruction. This is a special problem in Indonesia where the highest marine diversity is found near to centres of high human population growth.

There are a number of recent reviews of threats to coastal systems (Fluharty 1994; Lundin 1993; Norse 1994; Suchanek 1994; Sebens 1994). These threats are: habitat loss; global climate change; over-exploitation and other effects of fishing; pollution (including direct and indirect effects of inorganic and organic chemicals; eutrophication and related problems such as pathogenic bacteria and algal toxins; radionuclides); species introductions/invasions; water-shed alteration and physical alterations of coasts; tourism; marine litter; and the fact that humans have little perception of the oceans and their marine life. The threats frequently are interlinked. All the reviews agree that the most critical threat is habitat loss. This is echoed in the recent Global Biodiversity Assessment (Heywood and assessment programme and discusses sampling designs which are appropriate to the measurement of the condition of a given habitat or area and finally discusses the types of managerial action that are needed to complete an assessment.

Another severe problem is that whilst habitats may ostensibly be maintained they become divided into small fragments. There is a large ecological literature on these so-called 'habitat islands' with theories of maintenance and loss of diversity within such islands (MacArthur 1967; Williamson 1983). Huston (1994) discusses this in a general context. Small 'habitat islands' that are remote from the main pool of species have higher rates of species extinctions and lower immigration rates than larger 'habitat islands' or 'habitat islands' that are nearer the main pool of species. Fragmentation of habitats is expected to lead to losses of species diversity. However, in marine coastal areas few studies have been done that quantify species loss with loss of a given area of habitat.

Horn (1975) and Connell (1978) have shown that diversity is often higher in habitats that are subjected to some disturbance than in undisturbed habitats, the "intermediate disturbance hypothesis". This is due to the disturbance creating space for new species to colonise. The spatial and temporal scales of the disturbance determine whether or not diversity increases or decreases. The species within a given habitat are adapted to the natural disturbance scales and are not necessarily adapted to man-made disturbances so that one cannot assume that man-made disturbance will increase diversity.

One important aspect that also needs to be considered is habitat restoration. On land there is a long tradition of restoring habitats, such as mining waste tips. There are some examples of habitat restoration in the marine environment, such as the well-publicised clean-up of the River Thames in UK where salmon can now be found in London. The developing science of restoration ecology should be a part of a strategy for conservation of coastal biodiversity.

4.2 Global climate change

Pernetta (1993) has reviewed the potential implications of climate change for a number of tropical areas. The most publicised consequence of global climate change is that of sea level rise with severe effects likely in the Maldives and Tuvalu which are only 2m and 4.5m respectively above sea level. Bangladesh is expected to lose 12 to 28% of its total land area over the next century as a consequence of predicted sea-level rise. Coastal wetland habitats are likely to suffer since wetland subsistence and formation probably cannot occur at rates of sea level rise above 10mm per year (Norse 1994). Wetland areas are important not only for the species they contain, their function as nursery areas, but also for stabilising coastlines and for protection against hurricanes and storm surges.

The most significant effect of global climate change on coastal systems is, however, likely to be altered due to storm events and rainfall patterns. It is predicted that the return period of storms will alter so that the 100 year storm occurs every ten years and the ten year storm annually (Houghton & Jenkins 1990). Such events are likely to be highly significant for nutrient transport to the coasts, for mixing processes in coastal areas and for current and frontal systems. As yet, the models available are not able to make sufficiently accurate predictions of likely consequences at regional levels, mainly because of the lack of data. A Global Ocean Observing System (GOOS) has been proposed to redress this lack of data and its implementation is being planned by UNESCO-IOC, UNEP and WMO. There are component modules on the Health of the Oceans (HOTO) and on the coasts.

The warming of the coastal ocean is known to lead to severe effects on corals. In 1983, 1989 and 1990 the surface temperature of the Caribbean increased by 2°C from 28-29 to 30-31°C with massive bleaching followed by death of corals. The species that died were important in structuring the reef so that the consequences were severe and extended over wide areas (see Sebens 1994 for a review). Similar events have been recorded in Panama and Indonesia but not with the widespread effects found in the Caribbean (Glynn 1990).

sought as souvenirs in many tropical areas and since they play key roles in controlling prey populations, their local extinction can lead to major changes in diversity (e.g., Paine's 1966 classic study on effects of removing keystone predators, but see Mills et al. 1993 for a critique of the keystone species idea). Many other species are heavily exploited and may be in danger but there is far too little information on which to make a proper evaluation. There is an urgent need for better information.

Marine mammal and sea turtle exploitation are well documented (see Norse 1994 for an introduction) and will not be treated in detail here. The species that are in danger are listed in the appendices to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

4.5 Pollution and marine litter

The GESAMP State of the Marine Environment Report (GESAMP 1990) is still the most authoritative statement of the threats to marine life. The report emphasises that coastal areas are affected by man almost everywhere and stresses that habitat losses from a wide variety of causes if unchecked will lead to a global deterioration of the environment. There is little that has happened since 1990 to suggest that things have changed for the better.

In recent years there has been a recognition that heavy metals seldom pose a threat to marine biodiversity, although there are local areas where high concentrations are still cause for concern, such as areas subjected to mining waste run-off and industrialised estuaries or fjords. There are major concerns about the long-term effects on marine populations of organic chemicals. PCB's and dioxins have been much in focus and there are recent concerns about the fact that many organic chemicals of quite different physical structures seem to mimic the effects of female oestrogenic hormones and have led to severe reproductive changes in terrestrial species (see review of Müller et al 1995). Clearly this is a topic where more research is needed before the threats to marine biodiversity can be quantified.

GESAMP states that eutrophication caused by excess nutrients and/or sewage discharged into coastal waters is an expanding problem and incidents are known from almost every coastal state. The initial effects are of altered species compositions both in the water columns and in benthic communities. This may lead to local changes in biodiversity. More severe effects due to low oxygen concentrations are mass mortalities (see Gray 1993). Other effects that have been linked to eutrophication are harmful algal blooms, but causal links to eutrophication are not yet proven. Nutrient abatement is recommended where eutrophication symptoms occur.

Ciguatera, a disease affecting the nervous and cardio-vascular systems, is caused by eating tropical fish that have bioaccumulated toxins from natural algae. Where algal biomasses are significantly elevated, such as in nutrient/sewage enriched areas, the risks of ciguatera are high; this is a common problem in Asia and the Pacific and affects 50,000 people per year (Hammond 1992). Other toxins produced by algal blooms affect coastal aquaculture and occasionally human health in both developed and developing countries.

Although oil is a highly visible pollutant and when spilled in large quantities can cause severe local effects (GESAMP 1993), it is not regarded as a significant pollutant on global scales.

Marine litter is an increasing problem for marine life and tourism. In the Mediterranean there are 3 main sources: litter from drainage sources on land; litter left on beaches; and litter discarded from ships including discarded nets and other materials from fishing vessels, UNEP (1991). Almost 75% of litter is plastic with Styrofoam; metal, glass and wood being the other major components. Turtles are particularly vulnerable to discarded litter. Of 51 carcasses stranded in Florida, 6% were entangled in nets and over 50% of Green Turtles *Chelonia mydas* had ingested debris which was thought to have been a major contributor to their deaths (Bjorndal 1994).

considerable efforts that the coastal zone has been highlighted as in need of conservation (Hildebrand, 1989; Wells & Ricketts, 1994).

4.10 Summary of threats

From this analysis it is clear that there are few threats to the open ocean and the threats are concentrated in coastal areas. Habitat destruction is particularly pervasive in tropical areas where mangroves, coral reefs and wetland areas are being destroyed at alarming rates. In temperate areas there are severe threats to wetland areas and estuaries and conflicts between industrial and tourist development and conservation are universal. The threats from commercial fishing on biodiversity of coastal areas has been neglected.

5 THE LEGAL FRAMEWORK OF BIODIVERSITY CONSERVATION

Apart from the Biodiversity Convention itself, the UN's Convention on the Law of the Sea (UNCLOS III 1982), which came into force in November 1994, is of major significance in relation to biodiversity. IUCN has recently produced a comprehensive analysis of the Law of the Sea and other legal issues relating to marine conservation (Kimball 1995). UNCLOS establishes a comprehensive framework for use of the ocean and its resources. In addition to UNCLOS, Kimball lists other international agreements that relate to fishing and conservation of marine resources, such as conventions on whaling, marine mammal conservation, regional seas, Antarctic resources, transboundary fisheries (e.g., salmon and tuna) etc.

Other important conventions include:

The 1971 Convention on Wetlands of International Importance Especially as Waterfowl Habitat, Ramsar (1971), and (1982) Protocol. (RAMSAR)

Convention Concerning the Protection of the World Cultural and Natural Heritage, Paris (1972). (UNESCO) - this includes the Great Barrier Reef and the Galapagos Islands.

The 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

The 1979 Convention on the Conservation of Migratory Species of Wild Animal (CMS)

There are many regional conventions and agreements protecting given coastal areas and Kimball (loc.cit.) lists these.

Application of these conventions alone will not lead to protection of coastal biodiversity. Most problems lie at national and local community levels where there are conflicting uses of coastal areas. Habitats such as mangrove forests have few supporters when economic pressures are applied. There needs to be a better understanding of the importance of preserving marine habitats by local citizens, managers, planners, economists and policy makers and enforcement of strong protective legislation if marine biodiversity is to be conserved.

6 HOW CAN MARINE BIODIVERSITY BEST BE CONSERVED?

Beatley (1991) reviews briefly how biodiversity can be protected in coastal environments, but the review lacks detail and contains no clear conservation strategy. Norse (1994) has produced "A strategy for building conservation into decision making". This covers the topic in a general way, but includes neither a strategy for conservation, nor an indication of the types of concrete action that are needed.

on an ecological time scale, either physically by fragmentation of habitats or artificially by confining species in aquaculture, then marginal populations occur with loss of genetic diversity. However, geographical isolation of viable populations over evolutionary time is a potent mechanism for speciation and increasing diversity (allopatric speciation). Stress associated with pollution also leads to selection of tolerant individuals and also results in loss of genetic diversity. To overcome the risks of loss of genetic diversity one needs to ensure open barriers to genetic exchange, that populations remain at optimal levels for genetic exchange and that a variety of breeds are maintained to sustain natural genetic diversity. Preventing habitat fragmentation will help in preventing the first of these risks.

Species and genetic diversity of deep sea benthic communities and microbial communities in general are largely unknown and these communities are likely to be rich sources of genetic diversity. The pelagic system has lower species diversity than benthic systems and as yet there are few known threats to biodiversity of the pelagic system of the open ocean, but atmospheric inputs of contaminants need careful evaluation. Coastal areas have a greater variety of habitats than the open ocean and coastal habitats are known to be highly diverse and yet the greatest threats posed are to these systems. Thus, in the context of marine biodiversity conservation it is coastal habitats that should have the highest priority.

The suggestion that in most communities there is functional redundancy, that is a smaller number of species can undertake biogeochemical cycling as efficiently as with the full species complement, has been refuted by two recent experiments. It is now felt that the higher the number of species the greater the efficiency of biogeochemical cycling may be the rule. However, both of these experiments were done in terrestrial systems and there is an urgent need to see whether marine systems show similar responses.

The greatest marine biodiversity occurs in the Indonesian archipelago and decreases radially from this area. The southern hemisphere has much higher biodiversity then the Northern hemisphere and Antarctica has higher biodiversity than the geologically younger Arctic.

Coral reefs, mangrove forests and wetland areas are being destroyed at alarming rates globally and these habitats have the greatest marine biodiversity. Yet there is an equal need to protect habitats with moderate and low biodiversity.

Losses of marine biodiversity are largely the result of conflicting uses of, in particular, coastal habitats, which lead to degradation, fragmentation and losses of habitats. The needs of a burgeoning population for housing, disposal of human and industrial waste, forestry, fisheries, development of harbours, industrial sites and tourist complexes are combined with effects from activities such as forestry or mining up watersheds often tens, if not hundreds, of kilometres away to degrade and destroy coastal habitats. It is habitat alteration, fragmentation and destruction in the coastal zone that is the central factor leading to loss of marine biodiversity.

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