A Framework for an Action Plan on Marine Biodiversity in Ireland

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by

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1.INTRODUCTION

As this century ends three priorities have emerged in environmental management, namely biodiversity, coastal zone management, and sustainable use of natural resources. At the United Nations Conference on Environment and Development (UNCED) in Rio, 1992, the nations of the world agreed that the basis for future economic development must be the maintenance of biodiversity. The Convention on Biological Diversity was signed at this conference and ratified by Ireland in 1996 (Department of Arts, Heritage, Gaeltacht and the Islands, 1998). These priorities are setting the agenda for the management of the marine environment and require people to broaden their understanding of the marine ecosystems and review their approaches to the use of marine resources. This report, with an emphasis on marine ecosystems, firstly defines biodiversity and how it can be measured, and indicates the reasons it is a priority for management. These reasons have been politically recognised at global and European levels, and the action required outlined. The various research approaches required to support management, especially with regard to nature conservation, are described.

Marine biodiversity is a priority for management because of the ‘goods and services’ it provides to humanity, including its major role in maintaining the global ecosystem. The services provided by the world’s ecosystems have been calculated to be 33,000 billion US$, of which 21,000 billion US $ is provided by the ocean (Costanza *et al.* 1997). Coastal seas provide 60 % of the ocean services. The services accounted for were nutrient cycling, recreation, cultural, food production, biological control, disturbance regulation, raw materials, habitats and refugia, waste treatment, and gas regulation. The ocean acts as a sink and buffer against rising levels of carbon dioxide which is a major factor in global warming.

The world is a blue planet because the sea covers about 70 % of the earth’s area and it is deeper than land is high. Because more than 51 % of the earth is covered by sea greater than 3000 m deep, most of the planet is dominated by deep-sea life (World Conservation Monitoring Centre 1992). This includes a remarkable diversity of marine life living in extreme conditions of temperature and pressure. While deep sea biodiversity is largely dependent on a rain of food from surface waters, it does include its own chemosynthetically based ecosystems around the ‘deep sea vents’. Life on earth originated in the sea, and there are fundamental differences in the physical and biological structure of marine compared to terrestrial ecosystems (Table 1). In this report, the consequences of the importance of biodiversity for the management of Irelands marine environment are outlined.

Table 1. Key differences between open-ocean and terrestrial ecosystems. Comparisons between these systems may provide insights into the general relationships between biodiversity and ecosystem function. In contrast, some marine and terrestrial systems may be similar in biological structure and would similarly benefit from comparison. This table is derived from the opinions in Angel (1992), Lasserre (1992), Anon. (1993), Hedlund *et al.* (1995), Steele (1998), and of the present author.

	MARINE	**TERRESTRIAL**
Physical structure determined by	Physical medium	Organisms
Weather system scale	Eddies 10-100 Km, last months to years	Cyclones 1000's km, last weeks
Temperature variation	Slow and moderate, restricted by medium	May be rapid due to air movements
Carbon cycle		
CO_2 residence time	1 month	25 years
Carbon store	large	small
Longest lived organisms	Top of food chain	Bottom of food chain
Dominant harvested resource	Predators (fish)	Plants and herbivores
Dominant primary producers	Small, motile, live for days to weeks	Large, fixed, live for years
Plant production (photosynthesis)		
Total biomass	Small	Large
Total production	Low	High
Chemosynthesis	Only source primary production in hydrothermal vents	No equivalent ecosystem
Growth of animals	Indeterminate	Determinate
Phylum diversity	High	Low
Species diversity	Low ?	High
Species dispersal	floating, swimming	wind-blown, flying

What is biodiversity?

Biodiversity is the variety of life and the interactions between life and the environment, a concept already generally appreciated by the public (Reaka-Kudla *et al.* 1997) although sometimes using different words, such as the 'living world', wildlife or nature. It can thus form a conceptual bridge between how the public and politicians perceive the natural world, and how scientists might describe it. This variety is a property of life, derived from DNA (Solbrig *et al*. 1992), but expressed in response to the environment. It is a characteristic of biology and ecology, rather than a single measurable parameter and scientists can use many indices in an attempt to measure it (e.g. Magurran 1988). The most frequently used and currently practical measure is the number of species, but this is not necessarily nor consistently correlated with other aspects of biodiversity, notably other biological units and interactions between these units (Figure 1).

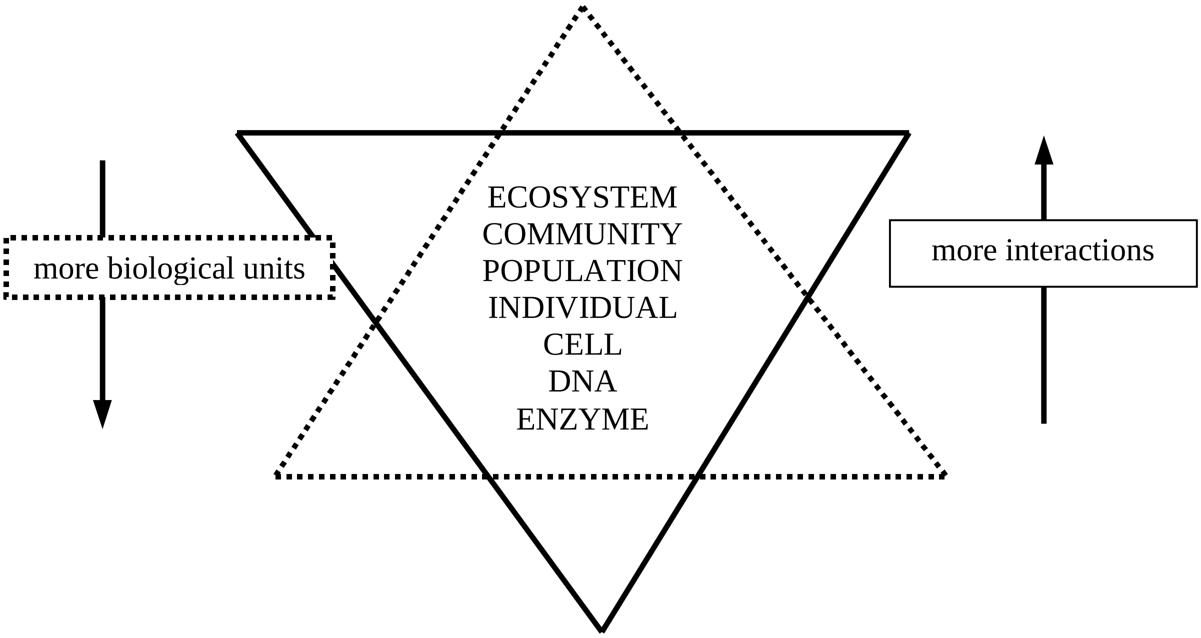

Figure 1. Biodiversity represents the variety of biological units and the variety of biological, biochemical, and biophysical interactions between these units. The complexity of interactions increases as one moves from cellular to ecosystem levels of organisation. The abundance of biological units increases as one considers smaller biological scales, from individuals to enzymes. Any single measure of biodiversity cannot be considered to be representative of all aspects of biodiversity.

Species are the only international standard unit with a controlled nomenclature for describing biodiversity. However, diversity within species is also important (Box 1). The expressed (phenotypic) and genetic (genotypic) diversity can be measured above and below the species level (Box 2). While the species concept is invaluable for plants and animals, it is not so useful for microorganisms. In some geographic areas, standard definitions of seabed biotopes (= habitat + its associated community) are now available, such as developed for Britain and Ireland (Connor *et al.* 1997a, b) and France (Dauvin *et al.* 1994, Dauvin 1995).

It must be remembered that it is not the number of species alone but the species composition that is the important indicator of diversity across spatial scales and habitats (Chapin III *et al.* 1997). Furthermore, species and ecosystems with 'low' biodiversity can be as important for conservation as those with 'high' biodiversity (Box 3). Indeed, most agricultural systems have lower diversity than if they are not farmed, and estuaries typically have lower diversity than rivers and fully marine waters. Biodiversity demands a holistic perspective of biological units and ecosystems. This ranges from the microorganisms (Box 4) to more familiar organisms such as fish and whales.

Box 1. Biodiversity at the intraspecific level.

The classical taxonomic 'species' boundaries only describe a limited part of biodiversity, so that conservation efforts that are restricted to this level of differentiation may cause an important loss of evolutionary relevant variation present at the intraspecific level. We need to know what diversity exists within a species, how this diversity is generated, maintained or lost, and at what level this diversity should be conserved. These questions entail a search for Evolutionary Significant Units (ESUs), historically isolated sets of populations that together encompass the evolutionary diversity of a taxon (Moritz 1994 a, b, 1996).

To generate biodiversity at the organism level it is necessary that genetic polymorphisms are established in populations. Some of these may be neutral and unrelated to the environment (e.g. black versus brown haired dogs), while others may be maintained by selection and directly correlated with environmental factors (e.g. different camouflaging colour morphs in insects). Some variation may represent environmentally induced phenotypic responses. Variation is inherent in populations and new variation may be protected, and thus contribute to future evolutionary change by the formation of reproductive barriers; the stronger the barrier the greater the impediment to gene flow between such separated populations. If we are to understand biodiversity it is important to understand how reproductive barriers are formed and hence how independent genetic entities arise within populations. It is also necessary to understand in what way habitat heterogeneity contributes to providing a framework within which variation is facilitated. Application of the ESU concept has the advantage that even if the taxonomic status of some populations or forms is still debated or confused these populations can nevertheless be considered for conservation. An extension of the ESU concept is to identify Management Units (MUs), namely sets of populations that are currently demographically independent (Moritz 1996), by focusing on particular habitats, or on isolated and peripheral populations. The application of the ESU concept provides direct guidelines for conservation actions and represents therefore a potentially very useful and practical tool for protecting biodiversity.

Box 2. Measuring biodiversity.

Phenotypic variation at different taxonomic levels can be assessed by analysis of morphological characteristics using both traditional measurements and computer-aided image analysis. This can be supplemented by transplantation experiments in the field. To provide a phenotypic estimate of biodiversity at the physiological level thermal or salinity tolerances of selected populations could also be measured. Genotypic variation can be assessed by protein electrophoresis and a number of DNA techniques. The former include starch gel electrophoresis, polyacrylamide gel electrophoresis, isoelectric focusing and two-dimensional electrophoresis of allozymes and general proteins. The DNA techniques involved are Random Amplified Polymorphic DNA (RAPD) fingerprinting, restriction site polymorphisms of nuclear and mitochondrial genes, Single-Strand Conformational Polymorphisms (SSCP) of mitochondrial and nuclear markers, screening of microsatellite DNA variation and nucleotide sequencing of nuclear and mitochondrial genes.

Box 3. Issues of low and high biodiversity.

The term biodiversity was coined by Wilson (1988) as a contraction of "biological diversity" biodiversity should not be thought of as referring only to "high biodiversity", it is, in fact, a measure of complexity at any level of biological organisation (Figure 1). A single celled animal such as an *Amoeba* has lower complexity (is less biodiverse at the cellular level) than a human. Populations of a species that have been through a "bottleneck" of small population size, tend to have low genetic variability (low biodiversity) whilst large populations tend to have higher genetic variability (high biodiversity). Simple communities composed of few species have low biodiversity whereas complex communities that are species-rich have high biodiversity.

There is no reason to assume that as potential resources for mankind, biosimple (low biodiversity) systems will prove to be any less valuable than biorich (high biodiversity) systems. Biological systems tend to become more complex with time, so high biodiversity is an inexorable outcome of evolutionary processes in the absence of stress. Simple communities, for example, may have experienced past perturbations (e.g. glaciation, floods, and historical human exploitation) from which they have not yet recovered. Since stressed biological systems are a common outcome of man's use of the environment, understanding ecological processes in stressed systems may be necessary if we are fully to comprehend and therefore ameliorate mans effect on the natural environment.

Box 4. Micro-organisms – a peculiar but important case?

Microorganisms represent an ill defined, highly diverse assemblage of unrelated organisms. Defining them as microscopic unicellular organisms produces a grouping which includes bacteria, viruses, and unicellular eucaryotes, plants (micro-algae), animals (protozoa) and fungi (yeasts). There is a massive level of diversity within the group: taxonomic, metabolic and physiological. The development of phylogenic studies based on genetic distinctiveness has shown that all life may be divided into three domains, Eucarya (comprising all eucaryotes from humans to yeast), Bacteria and Archaea. The latter are both confined to the group loosely defined as bacteria. Thus within the bacteria alone we find two of the three domains of life, all forms of energy yielding metabolism (utilising sunlight, organic material or reduced inorganic compounds) and representatives capable of existence at all points throughout the range of physical and chemical conditions capable of supporting life. Microorganisms are found in all marine environments from the low temperatures and high pressures of the deep ocean to the high temperatures and potentially toxic environments of hydrothermal vents. Because of their unicellular nature, they may respond rapidly and dramatically to environmental change. Under suitable conditions their rates of metabolism and reproduction are orders of magnitude faster than those of multicellular entities. Bacterial biomass and population structure may respond in a matter of hours to environmental changes: diurnal changes have been well reported. Microorganisms typically occupy the lower trophic levels of marine food webs where their biomass and abundance will be significantly greater than that of the visible plants and animals. They are thus of profound importance in ecosystem functioning and in biogeochemical cycles where they are a key factor in such processes as global warming. Primary production is typically carried out by microorganisms (phytoplankton) whose biodiversity and activity will ultimately influence fish stocks. Other areas where an understanding of marine microbial biodiversity impinges on human activities include the development and control of algal blooms, the fate of pollutants and bioprospecting.

In spite of this, microorganisms (especially the bacteria) are rarely included in biodiversity surveys. Whereas those dealing with marine macro-organisms are faced with tens to hundreds of individuals per cubic meter, the abundance of microorganisms will be several orders of magnitude greater. Because of their small size and the lack (in many cases) of morphological or visible structural characteristics, methods of classification and sorting etc. such as would be used in studies of plant or animal biodiversity are of limited use. A system of bacterial taxonomy has therefore developed which was based on function rather than structure. The system was pragmatic, with most attention being paid to organisms of industrial or medical significance, and had little or no relationship to phylogeny. The species concept was of little significance. Methods of identification relied on the ability of isolates to grow on liquid or solid media. This was a major barrier to meaningful biodiversity studies. Typically only a small (<3%) unrepresentative fraction of marine bacteria may be isolated in this way. Of this fraction, it was only practical to identify a small sample. All these factors have, until recently, restricted the microbiologist's involvement in biodiversity studies. Those studying microalgal and protozoan biodiversity may make use of morphological characteristics (though a lack of protozoan expertise is a considerable limitation), but bacteriologists and virologists were typically restricted to monitoring the distribution of a few very limited types (typically indicators of sewage pollution).

The use of nucleic-acid-based methods is revolutionising microbial taxonomy and is poised to do the same for biodiversity. By comparing the nucleotide sequences of a specific fragment of the genome (typically that coding for ribosomal RNA) a taxonomy based on phylogeny is developing. Selective amplification (by PCR) of rRNA genes in an environmental DNA extract provides material which is a true representation of the biodiversity of the microbial population. Methods must now be developed to deal with the mass of information which this material contains. Several potentially effective approaches are available. Databases of sequence information are rapidly expanding and provide a framework by which sequences derived from samples may be assigned to a taxonomic niche, even if (as typically occurs) they represent previously unknown organisms. Unfortunately the use of a cloning and sequencing approach restricts the researcher to classifying a minute, though random, fraction of the population. Other approaches (T-RFLP and DGGE for example) provide a synoptic "fingerprint" of community structure, but deal with ill defined "operational taxonomic units". Molecular probes provide an easy and powerful way of monitoring temporal changes in specific components of the microbial community, but require some prior understanding of its biodiversity. At present the best approach to studying biodiversity is to use a combination of these approaches, but this restricts investigations to a relatively small number of samples. Perseverance with this approach, however, will provide the basic information on the biodiversity of the microbial community that is presently lacking and will lead to the establishment of methods which will be easier and more effective that those presently used by macrobiologists and may eventually be adopted by them.

Article 2 of the Convention on Biological Diversity defines biodiversity as the variability 'within species, between species, and of ecosystems'. The within species aspect of biodiversity can be measured at an individual and population level using morphological, physiological, and genetic parameters. The between species or community level diversity can be described using a range of so-called diversity indices, such as species richness, indicator species (e.g. dominant, keystone), rank abundance plots, and evenness, and life history characteristics or traits. There is no consensus as to which of the 'diversity' indices is a better descriptor of diversity. Furthermore, one cannot interpolate from the distributional richness of one group of species to another (e.g. Lawton *et al*. 1998). However, at least species composition and richness should be described. Describing ecosystem diversity demands measuring its functional attributes. This could include the spatial extent of biotopes, guilds present, trophic structure, microbial, plant and consumer production, mass balance modelling, nutrient cycling, physical and chemical properties of the system, and rates of energy flow.

Why is biodiversity important?

Biodiversity is important and needs conservation for economic, ecological, moral, social and legal reasons (Table 2) (e.g. Ehrlich and Ehrlich 1992, Wanden and Schuber 1998). It is the basis for all life on earth, providing food for man, and healthy ecosystems that sustain this food supply (Pimentel *et al*. 1997, Daily *et al.* 1997). The loss of each piece of biodiversity, especially at the species level, reduces the options for

(1) nature to adapt to the changing climate (e.g. for species to replace each other according to changes in climatic conditions such as temperature).
(2) people to adapt their food sources to different environmental conditions (including climate change), and
(3) people to discover and gain new benefits from biodiversity.

Table 2. Fifteen economic, ecological, social, moral and legal reasons why society needs to protect and manage biodiversity.

Economic

- It is essential for the assimilation and recycling of wastes derived from human activity
- It is the source of food for man and domestic animals
- It provides valuable recreational resources
- It contains biotechnological resources of increasing commercial and medical importance
- It produces non-living resources of commercial importance such as maerl, coral, coal, oil, gas

Ecological

- It supports economic resources through the food chain and interaction between species
- It maintains local to global ecosystem health through its interaction with the physical and chemical environment (e.g. athmospheric carbon dioxide, oxygenation) and can buffer the world against climate change

Social

- Aesthetic value aids relaxation, a source of inspiration for art, science and philosophy
- Educates people about how the living world evolved and its complexity
- Strong cultural and historical value for society including symbolism in religion and folklore
- Indicator of climatic change, within and between years
- Indicator of quality of abundance of natural resources

Moral and ethical

- It is generally accepted that other life forms have a right to exist, and that man has a responsibility of stewardship to protect our natural inheritance for future generations
- The production of unnecessary waste and thus pollution can be considered immoral

Legal

- The Convention on Biological Diversity and other laws now places a legal obligation on countries and their citizens to protect and sustainably use biodiversity

Orians (1998) reviews persuasive research indicating that humans have a genetically inherited appreciation of good habitats, such that diverse and productive habitats are aesthetically pleasing. The fact that the public do value biodiversity in more than monetary terms is demonstrated by the increasing popularity of nature programmes on television ranging from gardening to wildlife, outdoor pursuits such as hill walking and scuba diving, and nature activities in schools and adult education programmes. The fundamental importance of biodiversity to human existence has been recognised in art, folklore, religion, literature and philosophy in all human cultures. A recent European survey found 73% of respondents felt society was obliged to protect biodiversity mainly for both moral and heritage (41%) and ecological (41%) reasons (Troumbis 1998). Only 2% stated for economic reasons. However, despite the increasing power of the consumer and public, society is primarily managed on an anthropocentric and economic basis.

Environmental non-governmental organisations and 'green' political parties are now a formidable influence in society reflecting growing public awareness and concern over the quality of the environment and food. Part of good economic planning involves taking out insurance against future, perhaps unforeseen, events. Maintaining biodiversity in nature is a form of insurance because this biodiversity may provide replacements for current food resources. While it is a reality that many third-world countries do not have, or cannot afford, this long-term insurance policy, this is not the case in Ireland. For whatever reasons, some individuals and elements of industry will not assist the maintenance of natural biodiversity. It is thus critical that government policy is followed up by enforced regulatory actions to ensure marine biodiversity is protected and used in a sustainable manner. The Convention and associated national regulations oblige authorities and people to protect biodiversity. This is essential because some people will not have the ability or willingness to understand the importance of biodiversity or their short-term perspectives will result in their activities reducing biodiversity.

The fact that biodiversity is valuable for different reasons is critical to its management. One use of biodiversity may have negative impacts on other. Trawling for fish may damage seabed life, and gravel extraction may alter habitats for commercial fish stocks. Although it is possible for people to live and produce food in low biodiversity environments, this does not mean other aspects of biodiversity are unnecessary. This is recognised in the Convention on Biological Diversity. High monoculture production of food requires significant human inputs and intervention to maintain it, including the use of fertilisers and biocides. In agriculture, this recently profitable farming is increasingly becoming unsustainable due to the economic costs of over-production. Nevertheless, some loss of biodiversity on at least local scales is inevitable with the increasing human population. The challenge is thus to balance societies short-term needs for food, health and recreation, against the long-term need to protect biodiversity for future generations. History suggests that we can have little idea of what uses and values future generations may discover in biodiversity.

What benefits arise from marine biodiversity?

Marine biodiversity has both direct and indirect importance to mankind. It provides food in the form of fisheries and aquaculture, and a recreational environment for tourism (Figure 2). Many species of marine life which are not directly harvested for food, are themselves food for fish and shellfish and thus key elements in the marine food chain. Pollution reduction will improve food quality, for example of sewage contamination of shellfish, and organochlorines in the food chain.

In addition to these reasons for protecting biodiversity, marine ecosystems provide other resources; including oil, gas, gravel, sand, transport routes, cooling water for power generation and industry, and wind and wave energy for electricity. Even the non-living natural resources of coal, gas, oil and limestone are the product of biodiversity, and these and living resources provide the raw materials for many of the products used by man (e.g. plastics).

Fisheries are the greatest source of wild food to mankind, in terms of quantity and protein (World Conservation Monitoring Centre 1992). Most fish production is in the higher latitudes, including the north-east Atlantic, while most species occur in tropical seas. Thus, while biodiversity in terms of species is lower in the north Atlantic than tropical seas, the within-species diversity of North Atlantic fish stocks is critical for the survival of fish of importance to man. Important fisheries in Ireland include cod, mackerel, herring, plaice, sole, haddock, salmon, crab, lobster, prawns, and shrimp.

Aquaculture is dependent on relatively few species for production, as is agriculture. Thus the within-species component of biodiversity of aquaculture is very important to maintain. This is probably more cost effectively maintained by ensuring the health of the wild stocks of the cultured species than establishing captive breeding stocks. Species of aquaculture importance in Ireland include oysters, mussels, clams, salmon, turbot, charr, rainbow trout, abalone, scallops, and eels. Some cultured species, such as mussels, *Mytilus edulis*, are derived entirely from wild juveniles, while farmed Atlantic salmon, rainbow trout, oysters and clams are hatchery reared.

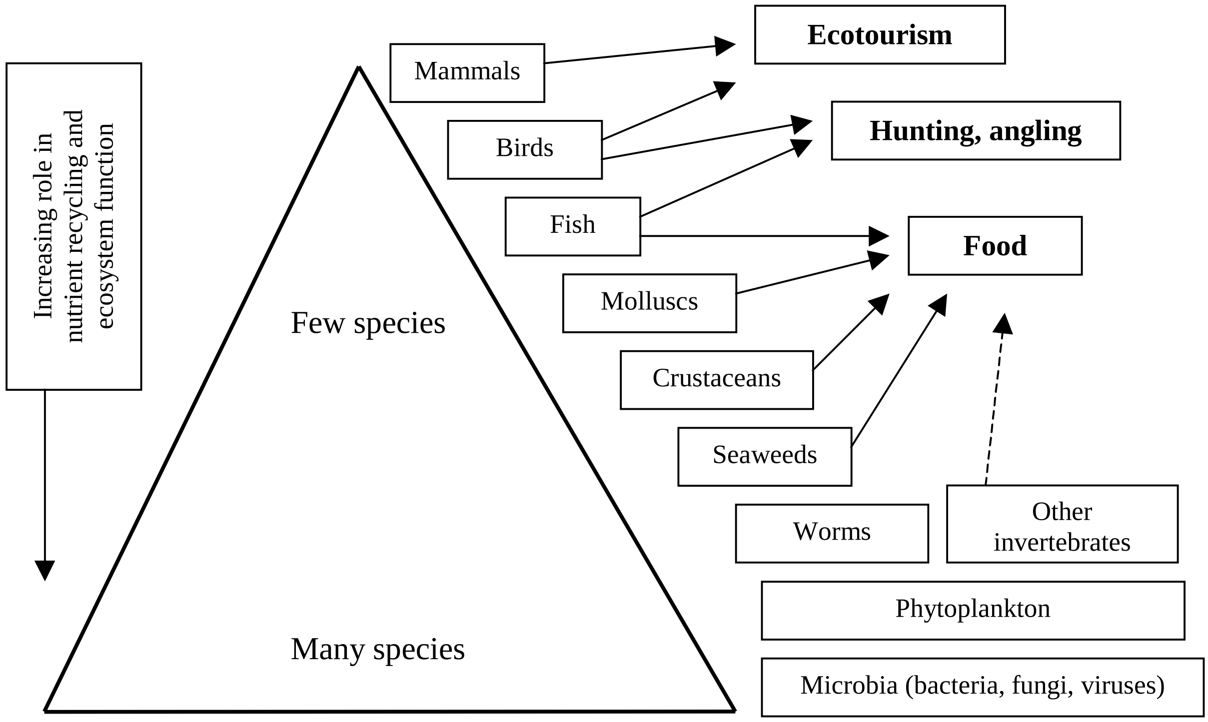

Figure 2. A diagram illustrating the relationship between different components of marine biodiversity and their uses to man. While it is easier to quantify the economic benefits of species higher on the pyramid, the lower part of the pyramid may be more important for the healthy functioning of ecosystems.

The increasing spread and urbanisation of the human population is placing greater value on natural areas for recreation. Marine biodiversity is of growing importance in Ireland: directly for angling, nature watching, scuba diving, and photography; and indirectly by providing a pleasurable and clean environment for activities such as water sports and boating.

Of less obvious importance is the key role that the biodiversity of marine ecosystems plays in providing food for directly harvested species, recycling nutrients (notably nitrogen, phosphorus and carbon), as a sink for other wastes man discharges to the sea, and its key role in global climate control (e.g. Grassle *et al.* 1991, Angel 1992, Daily *et al.* 1997). Recent research suggests that a rich biodiversity promotes stability in ecosystems (Chapin III *et al.* 1997). Research in experimental grassland (Naeem *et al*. 1994, Tilman *et al*. 1996) and freshwater microbial microcosm (McGrady-Steed *et al*. 1997, Naeem and Li 1997, McGrady-Steed and Morin 2000, Naeem *et al*. 2000) ecosystems, has demonstrated that (a) nutrient cycling is more efficient and consistent, and (b) production and stability (i.e. resilience to change) greater, where more species are present. Hulot *et al*. (2000) found the effects of nutrients in freshwater lake mesocosms to only be predictable when more complex trophic interactions were modelled, demonstrating that simple linear food interactions are not how ecosystems operate. However, the mechanisms for these effects, notably the importance of species numbers over species composition, and the effects of spatial scale are not yet clear (Waide *et al.* 1999). Comparable experimental studies have yet to be conducted in marine ecosystems (Boucher 1997). However, current scientific thinking is that it is biodiversity that maintains the balance of nature against a background of physical change (e.g. storms, seasons, climatic).

The ocean is a physical (temperature) and chemical buffering system against global climate change, including absorption of carbon dioxide from the atmosphere and storing carbon in sediments. It holds 15 and 50 times more carbon than is on land and in the atmosphere respectively (Lasserre 1992). All atmospheric carbon dioxide passes through the ocean every 8 to 10 years, and 30-50% of this goes through a "biological pump" (i.e. controlled by marine life). These benefits to society are enormous (Costanza *et al.* 1992) and are provided at no financial cost. In contrast food production from land must pay for the land, maintenance of soil quality, and food for farm animals. Because of these hidden benefits, marine biodiversity is undervalued by society. This value will be more apparent when the availability of the 'goods and services' of marine biodiversity is reduced.

Considering the rapid development of human technology, it is prudent to assume that future generations could identify and use marine biodiversity in ways that are not anticipated at present. For example, while a wide range of pharmaceutical products has been derived from terrestrial biodiversity, there has been less marine 'bioprospecting', although it is underway (Box 5). Yet, the greater phylogenetic diversity of marine life suggests that a greater diversity of biochemical compounds and pathways are likely to occur in the sea. For example, a group of bacteria-like organisms which are adapted to living in extreme environments, the Archaea, are almost entirely marine. Their remarkable specialisation such as growing at conditions of 113 ºC, pH near zero, anaerobic and high salt concentrations and combinations of these conditions (Jarrell *et al.* 1999), indicate the unique contribution they may directly (genetics) and indirectly (new enzyme and biochemical pathways) make to biotechnology. There is thus a responsibility on society to protect all parts of biodiversity, and on governments to ensure it is sustainability managed. The costs of protecting this biodiversity that is not directly harvested will be far less than the cost of its restoration (Pimentel *et al.* 1997).

For people in the present and future, it is essential to conserve marine biodiversity to supply food (fisheries, aquaculture), ensure a pleasurable life (recreational uses) and ensure healthy ecosystems that recycle nutrients and buffer against climate change. Elements of biodiversity not directly used by man are indirectly used as part of the food web. Species that are of limited ecological importance at present provide a form of insurance, as under future climate conditions they may become important (Hanski 1997, Holmes 1998). This "biodiversity insurance hypothesis", has been supported in experiments in terrestrial grassland microcosms (Hanski 1997, Naeem and Li 1997), and re-analyses of other studies (McGrady-Steed *et al.* 1997).

Box 5. Bioprospecting for marine bioactive products.

In 1997 the pharmaceutical and chemical industries were responsible for Irish exports worth £8.8 billion. This was equivalent to 25% of all exports and represented an increase of 54% during the previous two-year period. Pharmaceuticals were the largest and fastest growing part of this sector, employing 11,900 people in plants representing 16 of the top 20 pharmaceutical companies in the world. Biotechnology now forms a major industry which uses biological processes to produce a range of products (enzymes, therapeutics, diagnostics, etc.). In order to expand and compete, these industries constantly seek novel or improved sources of products. Bioprospectors collect a variety of organisms or genes of potential use. Bioscreening then selects out those with the most desirable characteristics. Sources may include microorganisms, plants or animals that may be harvested or cultured. Valuable genes from any source can be inserted into suitable microbial hosts and expressed in an industrial environment. Alternatively the structure of bioactive compounds may be investigated and effective analogues synthesised chemically. These approaches thus avoid any impact on natural environments or resources.

The sea provides an ideal environment for bioprospecting. It contains a wide and largely unexplored diversity of life. It also contains a diversity of environments, yielding organisms with unusual and potentially valuable characteristics. Valuable products of marine origin, which have already been discovered, include anti-microbial and anti-tumour agents, enzymes with novel characteristics and food additives. Marine bioprospecting would be of great benefit to Ireland and Europe, both as a job and wealth-creating enterprise in its own right and as a means to encourage the establishment of "green", skill-intensive biotechnology based industries.

Biodiversity studies should play a key role in the promotion of bioprospecting by:

- Assessing and demonstrating the potential of marine ecosystems as sites for bioprospecting;
- Providing diverse collections of organisms and genes (as environmental nucleic acid extracts or sequence databases) for bioscreening.

To maximise the benefits of bioprospecting to Ireland, it is essential that new schemes and mechanisms are developed to encourage collaboration and exchange between the pharmaceutical, agrochemical and other biotechnologically based industries and scientists potentially involved in bioprospecting and bioscreening (marine biologists, microbiologists, molecular biologists, biochemists, chemists and physiologists).

Box 6. Exotic species and biodiversity.

Exotic species are those organisms that are found outside of their natural range, often referred to as alien, non-native and introductions. The majority of exotic species are benign but a small proportion of them can have a wide range of economic effects that may have impacts on food production, recreation or habitat modification. These effects are perceived as either beneficial, as in the case of some farmed foreign molluscs, or harmful as in the case of acquired pests, parasites and diseases. However, it is difficult to apportion many species as being either native or exotic. This is because the world became widely travelled by sailing ships before the development of species taxonomy.

The majority of species are moved by ships either as hull fouling or by the water used on ships in special dedicated ballast tanks between different world regions. In this way large numbers of species in varying abundance become transported beyond their normal range, most usually to port regions. Many become transported to other port regions to create a series of disjunctive populations or they can spread by dispersal stages. A species introduced by a ship may also be spread by different vectors, including trade in cultured molluscs and small craft movements. In Ireland the greatest known number of marine exotics occur in Cork Harbour, a major shipping port that lies within a sheltered bay. Here the added component of species increases biodiversity.

The aquaculture industry benefits from production of several exotic species, including rainbow trout, Manila clam, Pacific oyster, European and Japanese abalone, and algae used in shellfish hatcheries. Trade in aquatic species has brought with it unwanted species that can modify aquaculture production, such as the blood parasite of oysters *Bonamia ostreae*. Some species that have been introduced deliberately and considered beneficial at that time, have since been ascribed as being harmful ecologically. There are thus projects to remove stands of *Spartina* grass to provide a greater feeding area for birds. Planned movements of exotic aquatic species, or of "transfers" of different populations, should now follow Code of Practice of the International Council for the Exploration of the Seas (ICES). By closely following these recommendations the risk of subsequent undesirable effects can be considerably reduced.

Management of exotic species by ships includes guidelines laid down by the International Maritime Organisation, which are reviewed from time to time. This unfortunately remains the most significant vector for species introductions and unwanted species now established elsewhere in Europe are now likely to become established in Ireland over the next century, such as the Japanese crab *Hemigrapsus penicillatus* and the Chinese mitten crab *Eriocheir sinensis*. Such species are likely to significantly modify habitats.

Why special concern over the state of marine biodiversity?

There is concern over the loss of biodiversity because man has affected the local environment for millennia, and is altering the global environment during this century. The movement of the sea has a physical power and certainty apparently unaffected by man, but this conceals a more vulnerable underwater biodiversity. There are increased pressures on marine biodiversity, including over-fishing and over-harvesting, introductions of exotic (or alien) species (Box 6), and widespread pollution (Table 3). Rapport and Whitford (1999) described examples of estuarine, freshwater and terrestrial ecosystems that did not recover once human impacts were reduced, and this is likely to apply similarly to some marine ecosystems.

The present rate of extinctions for land and freshwater vertebrates (at least) is about 10,000 times greater than in the fossil record (Trweek and Pienkowski 1996). Analysis of the rate of recovery of species diversity after extinction in the fossil record indicates that the present unprecedented rate of extinction caused by man will probably take 10 million years to recover (Kirchner and Weil 2000). Although the ocean is much larger in area than areas most impacted by man, namely the land, continental shelves, are smaller in area (28 x 10^6 km²) than forested areas (38 x 10^6 km²) (Carlton *et al*. 1999). Coral reefs (0.6 x 10^6 km²) occupy only 5% of the area of tropical forests (Carlton *et al*. 1999). Impacts on marine habitats are not as visible and losses of biodiversity are not as easily quantified as on land. Descriptions of trawl disturbed seabed biotopes and rubbled coral reefs are not as striking as aerial photographs of clear-felled and burning forests but they are comparable (Watling and Norse 1998). Nonetheless, habitats impacted by man in the sea are as equally threatened by human activities as land habitats. The same ecological theory used to estimate rate of extinction in tropical rainforests suggest 1,000 of the described, and 60,000 including undescribed species, have gone extinct due to the destruction of 5% of the worlds coral reefs (Carlton *et al.* 1999).

Present management measures are failing to sustain fisheries resources (e.g. Botsford *et al*. 1997, Folke *et al.* 1998). Indeed the FAO (1994) has identified over fishing, and over investment in fishing, as the single greatest causes of degradation of marine resources and the primary cause of a reduced global catch.

Table 3. Why there is special concern over threats to marine biodiversity.

Increased pressures	• No part of the ocean unaffected by human activities • Widespread pollution • Contamination of human food supply • Over-fishing • Over-harvesting • Introductions of exotic (alien) species • Increased exploitation of offshore and deep-sea resources
Untapped resources	• Biotechnology applications • Aquaculture
Knowledge base	• Less studied than terrestrial environment • Less visible, accessible and understood by wider public • Many undescribed species even in Irish seas • Inventories and maps of seascapes and resources primitive compared to land maps • Remarkable new habitats being discovered in Irish waters, such as the living deep-sea coral reefs formed by *Lophelia*
Management	• Complexity national and international laws, regulations, conventions, commissions, and other agreements

All wastes, whether emitted to freshwater, land or air, ultimately end up in the sea (Figure 3). The most critical source of contamination of human food is through wild fish (European Commission 1996), because in contrast to farmed animals, they live and feed in the open environment. The sea connects local, regional to global ecosystems such that pollution and biodiversity must be considered in this range of spatial scales.

Predictions of what uses man may make of the sea and marine resources in years to come are too general for a full environmental impact assessment. The advance of technology and changing global economics may result in the sea becoming as closely managed as the terrestrial environment. For example, the present state of development of modern fish farming was not predicted 30 years ago. Thus it is naïve to assume that mankind will not invent new uses of marine biodiversity in the years, centuries and millennia to come.

Climatic change is already affecting marine ecosystems, including the north Atlantic, with concomitant effects on plankton, fish stocks, and bird and trout populations (e.g. Forchhammer *et al*. 1998, Elliott *et al*. 2000).

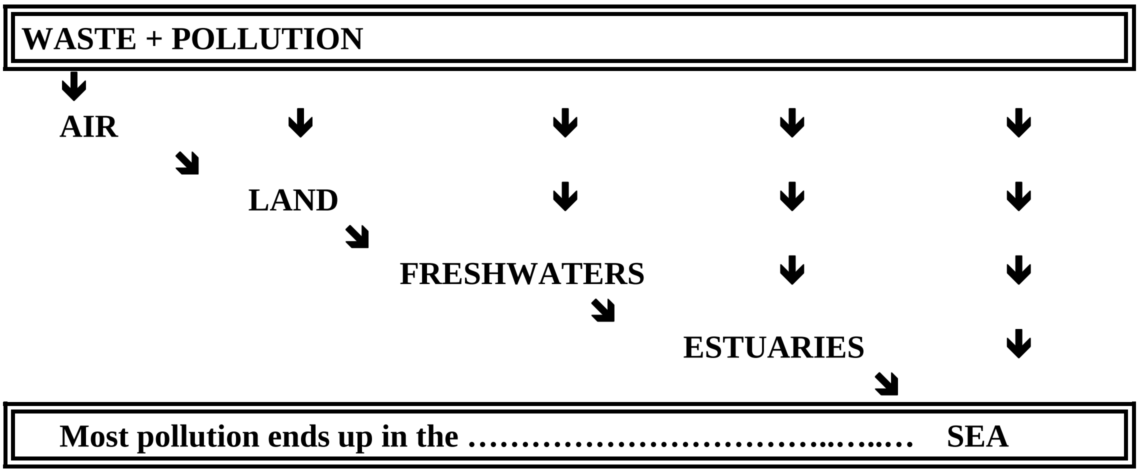

Figure 3. All wastes, contaminants and pollutants eventually end up in the sea from which it is impossible for man to remove them. Yet, the most important source of wild food eaten by people and farmed animals is marine biodiversity, notably fish, and these fish are directly exposed to these contaminants. A priority of pollution control must thus be to prevent the release of persistent contaminants into the environment and their entry into man's food chain.

There are particular difficulties in managing marine as compared to terrestrial and freshwater biodiversity. Of these environments, the marine is the least visible, least documented, least understood, and least constrained. It is underwater and under explored, and compared to land, it is under developed. Its management is divided by a complexity of national and international legislation and management authorities. Marine and coastal zone management typically crosses administrative boundaries at local and international scales.

As an example of the poor basic information on marine biodiversity, the rate of species discovery continues even in the best-studied seas. The small taxa, notably polychaetes, copepods, nematodes, and oligochaetes, are the poorest known but the richest in species (Figure 4) (Costello *et al.* 1996). Indeed, these taxa already contain almost half the species around Ireland (Table 4), indicating that the least known taxonomic groups are the most diverse. On a global scale, evidence indicates that most marine species are undescribed (Hay and Jumars 1999). The least well described groups of marine species are smaller in body size but have many species (Costello *et al*. 1996), and tend to have short-lived free-living dispersing larvae and small geographic ranges (Reaka-Kudla 1997). These features indicate they are more likely than the better known large marine animals (e.g. large fish) to have many endemic and undescribed species. Such endemicity means that many small marine invertebrates are vulnerable to extinction (Reaka-Kudla 1997).

The apparently fewer known extinctions of marine compared to land and freshwater species is probably because man has only significantly impacted the marine environment during the 20th century. However, the patterns of extinction are the same, with larger and predatory species being driven extinct first on land and sea (Malakoff 1997). Examples of marine extinctions in the Atlantic include the Atlantic gray whale, West Indies monk seal, sea mink, Labrador duck, great auk, and Canary Island oystercatcher (Carlton *et al*. 1999). Human activities have caused the extinction of at least three species of mysid crustaceans in the Mediterranean during the 20th century (Wittman 1999). Endemism, fragmentation of habitats and populations and populations densities below which spawning is unsuccessful (e.g. white abalone in California, Carlton *et al*. 1999), can occur in marine as well as terrestrial environments. For example, Myers (1997) found endemism to occur as often in shallow-water marine amphipods as in terrestrial plants in Pacific islands, suggesting similar processes influencing speciation in both environments. Some marine extinctions have probably already occurred but gone unnoticed (Watling and Norse 1998). A century of bottom trawling in European seas may already have caused some species extinctions (Roberts and Hawkins 1999). Carlton (1993) considered four species of marine gastropods (snails) to have gone extinct within the past 200 years. These examples illustrated that the lack of adequate description of species and information on their distribution mean that many marine extinctions may have gone unnoticed (e.g. Wittman 1999 for mysids). The results also suggest that species with narrow habitat requirements (e.g. dependant on other species) were most sensitive to extinction.

The difficulty of exploring the deep-sea is being overcome with new technology. The ocean is earth's 'inner space' and last great frontier of discovery on earth. Man first reached the bottom of the sea in 1960, only one-year before man first orbited the earth. In Irish waters, remarkable living deep-sea coral reefs have recently been discovered in a 1200 km^2 area of the Porcupine Basin, at depths of 600 to 700 m, some 200 km to 400 km from the west coast of Ireland (Henriet *et al.* 1998, Costello 1998, Box 7). Other recent discoveries in marine biodiversity include (Lasserre 1992, Heip *et al*. 1998):

- 3 new phyla discovered since 1980, e.g. Loricifera in 1983, Vestimentifera in 1985 and Cycliophora in 1995 (Winnepenninckx *et al*. 1998);
- a new ecosystem, "deep sea hot vents", where primary production is based on energy from chemosynthesis instead of photosynthesis, and where abundant unique communities occur;
- viable bacteria living hundreds of metres inside sediments at high temperatures and pressures;
- the smallest microscopic photosynthetic organisms in the world (0.6 µm *Prochlorococcus* and *Synechococus cyanobacteria*) occur in the ocean and they contribute 10-80 % of the primary production in over about 75% of the sea (Fuhrman and Campbell 1998);
- less than 5 % of the species of marine bacteria have been described.

The seabed in Europe has been trawled to over 1,000 m depth since the 1970's (Connolly and Kelly 1996), and oil and gas exploration can now operate down to 4,000 m depth and extraction to 2,000 m (Costello 1998). Video observations show the seabed at depths below 1,000 m to be criss-crossed with trawl tracks, and trawling (Rogers 1999) has already damaged recently discovered deep-water coral reefs. These reefs, mainly composed of the coral *Lophelia pertusa*, are remarkably large structures (Freiwald and Wilson 1998), with a biodiversity comparable to shallow-water corals (Rogers 1999). It is reasonable to assume that soon technology will allow more people to extract and harvest more resources from the deep-sea, and to visit there for education and recreation. The economic value of the deep-sea to mankind is thus increasing, and with that the pressures on its biodiversity.

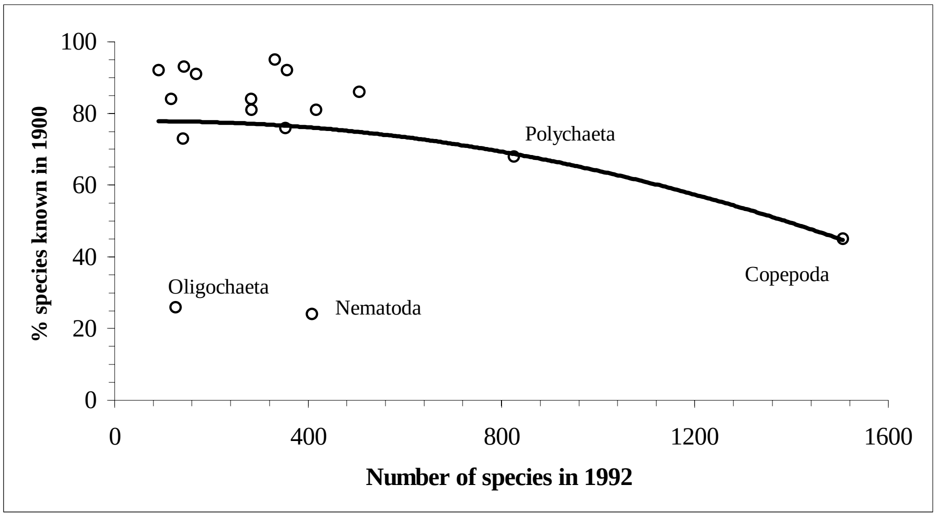

Figure 4. Relationship between the number of species known in certain taxa (as in Table 4) known to occur in Ireland and Britain in 1992 and the proportion of these species known to science in 1900 (best-fit trend-line shown).

Table 4. The number of marine species now described for the larger taxonomic groups in British and Irish waters (from Costello *et al.* 1996). The percentage of these species known in 1900 is also given. The groups with most species are the least well known.

TAXON	Common names	Number species in 1992	% known in 1900
Pisces	Fish	331	95
Echinodermata	Starfish and sea urchins	143	93
Anthozoa	Anemones	91	92
Bivalvia	Two-shelled molluscs	357	92
Decapoda	Crabs, prawns, lobsters	168	91
Gastropoda	Snails	506	86
Bryozoa	Sea mats	282	84
Tunicata	Sea squirts	117	84
Medusozoa	Jellyfish	283	81
Amphipoda	Amphipod shrimps	417	81
Porifera	Sponges	353	76
Nudibranchia	Sea-slugs	141	73
Polychaeta	Paddle worms	826	68
Copepoda	Copepod crustaceans	1506	45
Oligochaeta	Worms	126	26
Nematoda	Round worms	408	24

Box 7. Biodiversity in the deep-sea.

Probably the most comprehensive description of our offshore biological resources, which includes both bathyal and true abyssal faunas, is contained in 'Les profondeurs de la mer,' the results of more than 30 years observations by the French scientist Le Danois (1948). Foreign researchers have assembled more recent data about faunal biodiversity in Irish waters and groups participating in national (e.g. Rice *et al*. 1991) or EU MAST (e.g. OMEX and ENAM) funded programmes. Since the inception of the State, deep-sea research by Irish scientists has traditionally been hampered by the lack of a national ocean going research vessel. While foreign research cruises have afforded an opportunity to Irish scientists, very little work has been done with the exception of John Patching's deep-sea microbiology work over the last 20 years in National University of Ireland, Galway. The new surveys of the Irish continental shelf (Marine Institute, personal communication) represents a unique opportunity to redress the lack of national effort and implement some biodiversity actions in the offshore sphere. Currently developing integrated mapping techniques will facilitate the production of predicted biotope distributions with a high level of accuracy. Irish capacity in this area, therefore, should be developed.

The recent discovery of extensive fields of carbonate mounds and cold coral reefs off the west coast of Ireland is of global significance. This hitherto poorly known ecosystem may rival the discovery of hydrothermal vents in terms of potentially unique geosphere-biosphere interactions. The reefs, found between 600 and 1000m, also support an extremely high associated biodiversity. This high biodiversity and the adaptations of the fauna to life in such a deep and dark environment suggest a great potential to discover biocompounds previously unknown to man. Increasing economic activity in the form of deep-sea fishing and oil and gas exploration, however, may be a threat to the corals.   There is a pressing need to develop and enforce sustainable management practices for such a valuable offshore resource. The Norwegian government, for example, has prohibited (through legislation) the use of bottom trawling in the vicinity of some reefs. Recently in court, Greenpeace have succeeded in forcing the British Government to protect the corals through the application of the EU Habitats Directive beyond their 12 mile limit.

Recognising the importance of this ecosystem in Irish waters, a joint Marine Institute/MRI, NUIG workshop was held in January 1999 to ensure Irish participation in the formulation of EU Fifth Framework research proposals focused on carbonate mound and cold coral reef research. This successful venture yielded three funded projects, one of which, the Atlantic Coral Ecosystem Study (ACES), has a considerable biodiversity component both in terms of species identification/enumeration and in dealing with offshore conservation issues. The sensitivity and vulnerability of the coral ecosystem will be addressed and will lead to recommendations about sustainable use. It is likely that these recommendations will include site selection and zoning criterion for MPA's (Marine Protected Areas), particularly multi-user MPA's. This project which begins early in 2000 will serve as a primer for offshore management and focus attention on biodiversity issues including conservation, exploitation and management.

Some suggested actions

- Determine to what degree Ireland can legislate and enforce legislation beyond the 12-mile limit, within the 200 mile Exclusive Economic Zone (EEZ) provided for under the United Nations Convention on the Law of the Sea (UNCLOS), and rights ceded under the EU Common Fisheries Policy.
- Investigate the management potential of multi-user MPA's as a method of zoning economic activities and prepare draft legislation to implement them.
- Support the National Seabed Survey and commit resources to developing Irish capacity for integrated mapping to facilitate comprehensive classification of Ireland's offshore biotopes.
- Commit resources to developing Irish capacity in deep-sea species identification and curation as a supporting measure for the development of a comprehensive national biocompound screening programme.
- Introduce measures to regulate foreign exploitation of Irish biological resources.

2.INTERNATIONAL RECOGNITION OF THE BIODIVERSITY CHALLENGE

The global agenda

The importance of and urgent need for action on marine biodiversity has been recognised at an international level. The (Rio) Convention on Biological Diversity aims to conserve all components of biodiversity, natural and farmed, so as to provide for a sustainable use of natural resources. It obliges nations

- to develop national strategies for conservation and sustainable use of biodiversity,
- to use biodiversity in Environmental Impact Assessment for planning and development,
- to identify activities likely to have significant adverse effects on biodiversity,
- to sustainably use biodiversity so harvesting does not result in a decline of biodiversity,
- to identify, monitor, legally protect, conserve, and restore biodiversity,
- to provide education and training in biodiversity,
- to conduct research into biodiversity,
- to establish special protected areas, and
- to take measures to control alien and genetically modified species.

The Convention covers both traditionally harvested natural resources, and the increasing 'bio-prospecting' of genetic resources for biotechnology. Because the latter often involves the taking of genetic resources from a 'Developing' country to a 'Developed' country, issues of ownership, patenting and royalties have been identified as needing attention.

At the 2nd meeting of the Convention in Jakarta (1995) the scientific advisory committee recommended that special attention be focused on marine and coastal biodiversity, the so-called 'Jakarta Mandate'. Following this Convention, several regional marine conventions and organisations in which Ireland participates (e.g. OSPARCOM, IMO, ICES, IOC, and UNCLOS) and national policies are now bringing the concept of marine biodiversity into environment management. Following on the Jakarta Mandate, the IUCN and WWF produced a guide to the implementation of the Convention (Fontaubert *et al.* 1996). This concluded that action should focus on five thematic areas:

1. integrated marine and coastal area management (IMCAM),
2. promotion and maintenance of marine protected areas,
3. sustainable use of living resources (e.g. fisheries, corals, seaweeds),
4. prior studies and a precautionary approach to mariculture, and
5. control of introductions of exotic or alien species.

This action would require

- monitoring of biodiversity,
- development of methods to better use and share genetic resources,
- countries to take responsibility for trans-boundary impacts (notably water pollution) which may impact on marine biodiversity.
- further research to assist its implementation.

It supports the general consensus that resource management should develop from single species (e.g. a fish stock) to more ecosystem based multidisciplinary approaches (Botsford *et al.* 1997). This will require a range of studies to establish general and specific methods for the sustainable use of living resources.

In Ireland, the Convention on Biological Diversity applies to all government departments, authorities and industry. Thus each sector is encouraged to develop its own guidelines on biodiversity management. Some sectors, such as the forestry company Coillte (Coillte Teoranta 1999), and Forest Service of the Department of Marine and Natural Resources (Iremonger 1999), have already done so. The Department of Arts, Heritage, Gaeltacht and the Islands will have particular responsibility in applying the nature conservation aspects of the convention. The present report provides the basis for an action plan for marine biodiversity. These documents describe policy, identify indicators, and outline the management action needed to conserve and enhance biodiversity within a framework of sustainable resource management. A similar approach is now required in other sectors, including agriculture, fisheries, aquaculture, mining, tourism, transport, planning, energy and nature conservation (e.g. European Commission 1998b).

The Convention and Jakarta Mandate require that a lack of scientific information or uncertainty shall not be used to postpone measures to avoid threats to biodiversity. This places the onus on developers, including both government and private industry, to provide the information to demonstrate that developments will not have impacts on biodiversity. To date this has not happened in Ireland for wild fisheries and offshore oil and gas exploration, but the latter do now require an Environmental Impact Statement.

The European Union strategy

On 4 February 1998, the European Commission (EC) produced a strategy document on biodiversity in the context of the Convention on Biological Diversity (European Commission 1998a). This was accepted by the EU Council (17 June) and Parliament (20 October 1998), and thus is now policy which the EC will implement. The Communication deals with each of the topics in the Convention of Biological Diversity. It encourages Member States to have Action Plans in place to implement this EU strategy. It notes the need for biodiversity to be addressed by all sectors, including fisheries, forestry, agriculture, energy, transport, tourism, and aid to developing countries. All EU funding measures, including Structural and Cohesion Funding, and programmes funding environmental management, research, and external aid, will need to support the sustainable use of biodiversity. The document states that cross-border co-operation within and beyond the EU will need to be strengthened to better manage biodiversity. The sections on research and fisheries are of particular relevance to marine biodiversity. The need for sustainable use of fisheries, protection of non-target species, establishment of fishing exclusion zones, and prevention of aquaculture impacts (especially in the intertidal) is mentioned.

The EU Strategy document provides criteria for the identification of priority areas of biodiversity research and management, in relation to species, biotopes and ecosystems. They include

- areas with high biodiversity, presence of endemic and threatened species, and/or which are important for migratory species,
- biodiversity of social, economic, cultural and scientific importance,
- areas which are representative, unique, or demonstrate key evolutionary or biological processes,
- species important as indicators, or of medicinal, economic or farming significance,
- genomes and genes of social, scientific and economic importance.

This emphasis recognises that Member States and the private sector already fund research to help exploit biodiversity, such that different management and research actions may now need greater attention. The European Environment Agency (EEA) will collate baseline data on the status, trends, pressures, and causes of biodiversity losses, and identify gaps in knowledge, within the EU and for other European countries.

Biodiversity conservation in the European Union

There is a variety of protected area designations that can be applied to marine areas in Ireland, critically reviewed by Hickie (1997). These include

- World Heritage Sites and Biosphere reserves (UNESCO),
- Ramsar sites (IUCN),
- Biogenetic reserve and European Diploma sites (Council of Europe),
- Special Protection Areas (EU Birds Directive)
- Special Areas for Conservation (EU Habitats Directive).

Other complementary conventions cover migratory species (Bonn, IUCN), species trade (CITES, IUCN), whales (IWC), and international seas (UNCLOS) (Fontaubert *et al.* 1996). The most important of these, because it addresses marine biodiversity and all habitats and species, is the 1992 European Union 'Habitats' Directive for the conservation of natural habitats of wild fauna and flora (European Commission 1992). The Habitats Directive applies not only to member states territorial waters (12 nautical miles from the coast), but to their Exclusive Economic Zone (EEZ) up to 200 nautical miles from the coast (Mielchen 2000). Not all member states have yet recognised this, and Greenpeace had to take the UK government to court to get this recognition (Mielchen 2000). The EEZ provides a legal framework under the United Nations Law of the Sea (UNCLOS) for countries, including Ireland, to manage and protect natural resources up to 200 nautical miles from their coast.

The Habitats Directive directly builds on the Bern Convention and aims to create a network of Special Areas of Conservation (SAC) called 'Natura 2000'. This will include sites designated under the EU Habitats and Birds Directives. It expects about 5-20% of each member state to become part of Natura 2000. Member states should protect habitats in proportion to the area of that habitat in their country. The annexes of the Directive list over 200 habitats, 278 plants, 175 birds and 193 other animals in need of protection, and priorities are asterisked. The criteria for selecting habitats at a national and community level include habitat area, naturalness, restorability, contribution to European network, and representativity. Species criteria are similar, and include degree of population isolation, range and size.

The criteria can be applied to marine habitats but there is unlikely to be sufficient data to apply similar criteria to marine species. Marine habitats are very broadly outlined in the Directive, and many are seascapes at a scale more appropriate to birds than to fish and invertebrates. It is anticipated that the BioMar-LIFE biotope classification (Table 5, Figure 5) will be applied in marine conservation management as part of the European Union Nature Information System (EUNIS). If surveys of marine areas use such a standard classification, at least at the higher levels of the hierarchy, this will facilitate mapping and analysing patterns in biodiversity at the biotope level. This classification will, however, need to be expanded as more biotopes are described in the N.E. Atlantic region.

Table 5. A checklist of the upper three levels (major habitat, habitat complex, biotope complex) of the BioMar marine biotope classification of Connor *et al.* (1997a, b). The species on rock may also occur on other hard substrata (e.g. shells, piers, shipwrecks). The number of currently described biotopes and sub-biotopes is shown in parentheses.

LITTORAL ROCK
- LICHENS OR ALGAL CRUSTS (9)
- EXPOSED (MUSSEL/BARNACLE SHORES)
  - *Mytilus* (mussels) and barnacles (7)
  - Robust fucoids and red seaweeds (3)
- MODERATELY EXPOSED (BARNACLE/FUCOID SHORES)
  - Barnacles and fucoids (7)
  - Red seaweeds (5)
  - Ephemeral green or red seaweeds (freshwater or sand-influenced) (3)
  - *Mytilus* (mussels) and fucoids (3)
  - *Sabellaria* (honeycomb worm) reefs (1)
- SHELTERED (FUCOID SHORES)
  - Dense fucoids (stable rock) (10)
  - Fucoids, barnacles or ephemeral seaweeds (mixed substrata) (8)
  - *Mytilus* (mussel) beds (mixed substrata) (1)
  - Rockpools (9)
  - Overhangs and caves (3)

LITTORAL SEDIMENTS
- LITTORAL GRAVELS AND SANDS
  - Shingle (pebble) and gravel shores (2)
  - Sand shores (7)
  - Estuarine coarse sediment shores (1)
- LITTORAL MUDDY SANDS
  - Muddy sand shores (4)
  - Littoral *Zostera* (seagrass) beds (1)
- LITTORAL MUDS
  - Saltmarsh (26 +)
  - Sandy mud shores (4)
  - Soft mud shores (3)
- LITTORAL MIXED SEDIMENTS (2)

INFRALITTORAL ROCK
- EXPOSED
  - Kelp with cushion fauna, foliose red seaweeds or coralline crusts (13)
  - Robust faunal cushions and crusts (surge gullies & caves) (10)
- MODERATELY EXPOSED
  - Kelp with red seaweeds (11)
  - Grazed kelp with algal crusts (3)
  - Sand or gravel-affected or disturbed kelp and seaweed communities (7)
- SHELTERED
  - Silted kelp (stable rock) (14)
  - Estuarine faunal communities (shallow rock/mixed substrata) (3)
  - Submerged fucoids, green and red seaweeds (lagoonal rock) (4)
- OTHER
  - Fauna and seaweeds (shallow vertical rock) (3)

CIRCALITTORAL ROCK
- EXPOSED
  - Faunal crusts or short turfs (3)
  - *Alcyonium*-dominated communities (tide-swept/vertical) (4)
  - Barnacle, cushion sponge and *Tubularia* communities (very tide-swept/sheltered) (5)
- MODERATELY EXPOSED
  - Mixed faunal turfs (4)
  - Bryozoan/hydroid turfs (sand-influenced) (9)
  - Circalittoral sabellaria reefs (1)
  - Mussel beds (open coast circalittoral rock/mixed substrata) (3)
  - Brittlestar beds (2)
  - Grazed fauna (moderately exposed or sheltered rock) (2)
  - Ascidian communities (silt-influenced) (3)
  - Soft rock communities (2)
- SHELTERED
  - Brachiopod and solitary ascidian communities (8)
  - Sheltered *Modiolus* (horse-mussel) beds (2)
  - Faunal turfs (deep vertical rock) (2)
  - Caves and overhangs (deep) (1)

CIRCALITTORAL OFFSHORE ROCK
- *Lophelia* (coral) reefs (1)

SUBLITTORAL SEDIMENTS
- INFRALITTORAL GRAVELS AND SANDS
  - Maerl beds (open coast/clean sediments) (4)
  - Shallow gravel faunal communities (2)
  - Shallow sand faunal communities (5)
  - Estuarine sublittoral gravels and sands (3)
- CIRCALITTORAL GRAVELS AND SANDS (3)
- INFRALITTORAL MUDDY SANDS
  - Seagrass beds (2)
  - Shallow muddy sand faunal communities (4)
- CIRCALITTORAL MUDDY SANDS (5)
- INFRALITTORAL MUDS
  - Angiosperm communities (lagoons) (2)
  - Shallow marine mud communities (4)
  - Estuarine sublittoral muds (7)
- CIRCALITTORAL MUDS (3)
- INFRALITTORAL MIXED SEDIMENTS
  - *Laminaria saccharina* (sugar kelp) and filamentous seaweeds(4)
  - Maerl beds (muddy mixed sediments) (3)
  - Oyster beds (1)
  - Shallow mixed sediment faunal communities (3)
  - Estuarine sublittoral mixed sediments (3)
- CIRCALITTORAL MIXED SEDIMENTS (3)

CIRCALITTORAL OFFSHORE SEDIMENTS (3)

Substratum → **Zonation ↓**	**Wave exposure →**	ROCK Exposed	Moderate	Sheltered	Mixed sediment	SEDIMENT Gravel, Coarse sand	Sand, fine to medium	Mud (> 30 % silt)
Littoral	Supralittoral	Lichens				Talitrid amphipods, oligochaetes		SALTMARSH
	Eulittoral	Ephemeral green & red seaweeds (low salinity)			Gammaridae (low salinity)	Barren	Polychaetes & bivalves, burrowing amphipods rare	Polychaetes, *Corophium*, *Hydrobia*
		Barnacles & *Mytilus* (mussel)	*Fucus*, limpet, barnacles	*Ascophyllum*	Sugar kelp & filamentous seaweeds	Burrowing amphipods, bivalves rare		
		Red seaweeds & *Corallina*	*Sabellaria* reefs	Mussel beds				
Sublittoral	Infralittoral	Sponges & bryozoa under kelp	Grazed rock under kelp	Silted under kelp	Submerged fucoids		*Zostera* spp.	
		anemones, sponges & colonial ascidians (wave surge tolerant)		fauna		Maerl		
		coralline algae & calcareous tubeworms (scour tolerant)	Brittlestar beds	*Modiolus* (mussel) beds				Burrowing megafauna *Nephrops*, seapens
				Serpulid (tube-worm) reefs		Hydroid-bryozoan (current swept)	*Amphiura* spp. polychaetes	
	Circalittoral	*Flustra*, hydroids *Alcyonium* (current tolerant)	*Sabellaria* reefs Rich faunal turfs	Axinellid sponges &brachiopods	Solitary ascidians (silt tolerant)	*Neopendactyla* Venerupidae	*Abra*, *Nucula*, *Corbula*, spionid poychaetes	*Beggiatoa*
Offshore		Insufficient information for classification						

Figure 5. A matrix with the most important habitat features on the axes. This illustrates the relationship of shore height (littoral) and sea depth (sublittoral, offshore) with substratum (rock and grades of sediment) and the exposure of rocky habitats to wave action. These factors distinguish biotopes at the upper levels of the classification. Within the matrix the characteristic species of the communities occurring in the habitats are indicated. See the detailed classification in Connor *et al.* (1997a, b) for full definitions and details.

The Habitats Directive required all States to have legislation in place to apply the Directive in 1994, and to have a review of their habitats and species completed by June 1995. States vary greatly in their rate of implementation of the Directive, but this is the first effort to legally protect marine biodiversity on a large spatial scale in Europe. By June 2004 all Member States must designate and complete management plans for their SAC. However, areas qualifying and proposed as SAC are regarded as legally protected even before full formal designation, and any developments in SAC require an environmental impact assessment (EIA). The philosophy behind the Directive is of conservation management, such that no new human activities are necessarily excluded from SAC unless they compromise its biodiversity. In Ireland, the Department of Arts, Heritage, Gaeltacht and the Islands is responsible for implementing the Habitats Directive under the European Communities Natural Habitats Regulations of 1997.

3.MANAGEMENT OF MARINE RESOURCES

To derive benefits from marine biodiversity the first step is the establishment of policies to guide management. This report contributes to this process. The next step is the part of identification of the resources, and some of these are known in a general way (Figure 2).

It has already been noted that the state of knowledge of Irelands marine resources lags far behind that of terrestrial resources. Thus baseline studies involving mapping of ocean conditions, habitats and species distributions, detailed inventories of species and environmental conditions in different localities are an essential requirement for management. These studies characterise biodiversity at one point in time. To determine variation in time, sampling must be conducted at a range of time-scales from day to night, high to low water, lunar and seasonal, to longer scales of many years. Monitoring change in biodiversity must include concomitant monitoring of local and regional environmental conditions, including climatic variation and human activities. Monitoring is a requirement of the Convention on Biological Diversity, and must encompass the different aspects of biodiversity, from commercially harvested species, to indicator species, and species of nature conservation importance.

Indicators are essential because of the practical difficulties in monitoring many aspects of biodiversity over time. It is critical that a suitable range of indicators are identified (Watt *et al.* 1998), and that their relationship to other parts of diversity and environmental change is understood. They should be reliably quantifiable, and represent biodiversity of economic, cultural, ecological and nature conservation importance. Examples of possible indicators include the distribution and abundance of:

- pollution sensitive species, such as dogwhelks and other gastropods which are highly sensitive to organotin pollution;
- species of commercial importance;
- species which dominate biotopes and ecosystems through abundance or their actions (e.g. predation);
- exotic (alien, introduced) species;
- biotopes and species of nature conservation importance.

Once marine biodiversity resources are identified, and perhaps already exploited to some extent, they need to be quantified in space (mapped) and time (seasonal and between year variation). Research is necessary to understand how the resource is renewed such that its yield and economic sustainability can be determined. Further research may lead to the development of improved harvesting methods, which in conjunction with market development, can lead to greater value derived from the resource.

The use of a resource cannot be viewed in isolation from its environment. The sea provides food, oxygen and living conditions for its natural resources, whether wild or farmed. The exploitation of marine living resources, which are an integral part of biodiversity, must thus involve research and assessment of the impacts of:

(a) variable environmental and climatic conditions on the resource availability and quality;
(b) other human activities (e.g. pollution) on the resource;
(c) resource use on the environment and natural biodiversity.

There is no ‘final’ step in managing marine biodiversity because it exists in a constantly changing world, both natural and economic. Management measures must thus include regular audits and reviews of the use of marine biodiversity to consider alternative and new ways of deriving benefits for society in the short and long-term.

Integrated Marine and Coastal Area Management

Marine biodiversity is most used and abused in the coastal seas. It is thus necessary for it to be managed as part of a wider system of coastal zone management (CZM). It is no longer acceptable to use natural resources without considering the environmental impact of such activities. In turn, it is not possible to manage biodiversity without considering the wider aspects of economic planning and development. For marine biodiversity this extends to activities on land that affect the marine environment (i.e. the “coast” lands).

The Jakarta Mandate encourages the use of Integrated Marine and Coastal Area Management (IMCAM). In practice this appears equivalent to "Integrated CZM". IMCAM first requires a national policy which considers local, national, regional and other international commitments (Table 6). A discussion document "Towards a CZM policy for Ireland" (Brady Shipman Martin 1997) has been debated and awaits implementation. Coastal resources are shared across spatial scales that may not be immediately apparent. This policy must plan to facilitate both environmental protection and local population needs, including economic development. Such an approach to sustainable development, including CZM, is being promoted for aquaculture in Ireland (Box 8). Local communities must be involved in CZM on a continuous basis, and be empowered to manage their local resources within the scope of policies and regulations established at wider levels.

Mechanisms for consultation between individuals and organisations should be open before, during and after developments. Too often consultation arises as an objection to a new development. CZM policy must actively promote openness, transparency, public education, and a building of public trust in the management system (Table 6). Without this the public will not understand the reasons behind decision making, and are thus less likely to become involved in, or support, such management. There will always be conflicts to resolve, but it is critical that authorities, large organisations and 'experts' do not let professional egos, and jargon, alienate the general public.

Rivers are generally the greatest source of natural and human derived nutrients and pollutants to coastal seas, so coastal management plans need to link with river catchment plans. The environment, technology and policy will change in time. Hence, administrative, political, and technical aspects of CZM must be flexible in the short term and adaptable in the longer term to change. Such change should be anticipated and critical external reviews of the success of CZM regularly conducted (e.g. every 3-5 years). CZM should not result in more bureaucracy and regulations, but rather a streamlining and integration of planning across sectors and government authorities.

Box 8. Aquaculture and biodiversity in Ireland.

Over the past 25 years aquaculture has developed as an important sustainable rural resource-based industry, contributing £60 million to the Irish economy in 1998 and creating some 3000 jobs predominantly in coastal communities. The development and marketing of aquaculture products revolves around Ireland's green, clean image. It is therefore in the interest of the fish farmer and the industry to promote the preservation of biodiversity in our environment.

In order to enhance the promotion of responsible, sustainable development, Bord Iascaigh Mhara (BIM) and the Marine Institute have developed CLAMS (Co-ordinated Aquaculture Management Systems). CLAMS will include stakeholders from other sectors of the community, and this aquaculture management plan can be incorporated into the coastal zone management policy of the area. Dúchas are presently implementing Aquaculture Zone Management Plans (AZMP) in coastal Special Protection Areas (SPA) and Special Areas of Conservation (SAC). These are to be researched scientifically and implemented under the Habitats (92/43/EEC) and the Wild-birds Directives (79/409/EEC). Any aquaculture operations found to be displacing wildlife shall be moved to an area where they do not have such an effect.

It is national policy to promote the sustainable development of the aquaculture sector by expanding the farmed production of fish and shellfish, through improved efficiency and production techniques and by diversifying the range of species under cultivation.

Table 6. The important elements in and requirements for integrated marine and coastal area management.

Planning
- coherent regional and trans-national policy and strategy (vertical co-ordination)
- integrated cross-sectoral planning
- anticipation of conflicts
- alternative options
- subsidiarity (decentralised decision making)
- bottom-up management (involve and empower local people)
- clear identification of sectoral responsibilities (including areas of joint responsibility)
- organisational and individual accountability for decisions
- based on factual information on natural, social, economic features of the area
- work with rather than against nature (e.g. coastal erosion).
- choose geographical area for management appropriate to issue being addressed (not for administrative or regulatory reasons).

Development
- co-ordination across sectors (horizontal)
- transparency of decision making
- sustainability defined by holistic and long term criteria
- compatability with nature conservation
- pollution reduction at source
- waste minimisation
- environmental impact prediction (modelling) and assessment
- adaptability of administrative and economic structures to environmental and technological change

Technical
- linking air, land, freshwater (river catchments) and marine systems
- multi-disciplinarity (integration of physical, chemical and biological information)
- identification of assumptions, gaps in knowledge, and priorities
- mapping (computerised and on paper) at range of connected spatial scales
- integrated monitoring of environment in time
- dissemination of information in forms accessible to public and other researchers
- regular critical review of data requirements and approach

Monitoring
- field sampling as well as laboratory analysis quality control protocols
- model for data analysis and interpretation
- response plan to deal with undesirable impacts and unachieved targets detected by monitoring

Social
- consultation
- building of trust between management and public.
- open participation and collaboration in decision making
- achieve consensus on basic issues (e.g. need to reduce pollution, need for recycling)
- promotion of understanding and awareness of environment, biodiversity and different peoples needs
- education of public at all levels and media

A weakness of the European Union Common Fisheries Policy (CFP) is the lack of local management of most fisheries, such that the 'tragedy of the commons' has occurred (i.e. where the lack of individual responsibility results in the over exploitation of a collective resource). The CFP can, but has not yet, integrated measures to protect the direct and indirect impacts of fisheries on the marine environment and biodiversity (European Commission 1999). However, in the absence of the CFP, the status of fisheries and the wider fishery impacts on the environment may be worse than they are at present. It is now EC intention to take a more precautionary approach to ensure sustainable exploitation, and to consider environmental impacts in fisheries management (European Commission

1999). This will involve restricting fisheries through a range of measures, including reducing fleet capacity, limiting fishing seasons, restricting catch size, use of more selective gears, transferable quota systems (e.g. Fujita *et al.* 1998), and establishment of no-take areas (perhaps within Special Areas of Conservation) (e.g. Orensanz and Jamieson 1998) (Box 9). Current fisheries research indicates that ecosystem based management of fisheries is necessary (e.g. Botsford *et a*l. 1997, Orensanz and Jamieson 1998) and this is being begun in some areas (Sherman 1991).

Box. 9. Marine Protected Areas as fishery exclusion areas

An increasing number of studies have examined the effects of excluding or greatly reducing fishing in defined marine protected areas (MPA). The primary effect of fisheries is to reduce the abundance of the larger fish in selected populations. Thus most studies find an increase in the number of larger fish in MPA (e.g. Alcala 1988, Garcia-Rubies & Zabala 1990, Francour 1991, Rakitin & Kramer 1996, Russ & Alcala 1996, Chapman & Kramer 1999, Nowlis & Roberts 1998). An increase in the number of fish species, fish abundance, fish biomass, and numbers of smaller fish, are also common benefits of MPA. Where data is available, fishermen report greater catches near MPA (e.g. Russ and Alcala 1996).

Most of the studies confirming the benefits of MPA to fisheries have been mainly conducted in tropical and sub-tropical seas, such as Mediterranean (Garcia-Rubies and Zabala 1990, Sasal *et al.* 1996, Francour 1991), Caribbean (Rakitin and Kramer 1996), Philippines (e.g. Russ and Alcala 1996), and New Caledonia (Wantiez *et al.* 1997). However, the benefits of areas closed to fisheries similarly apply to north-eastern Atlantic waters (Horwood *et al.* 1998). The benefits will vary between fish species, fish sizes, the duration of the fishery closure, and the relative intensity of fishing pressure outside the MPA (e.g. Horwood *et al.* 1998, Nowlis and Roberts 1998).

For a given species, larger fish produce significantly more eggs and thus contribute more to population growth than an equivalent number or biomass of smaller fish. Thus the larger fish living in MPA's can contribute significantly to the production of young fish which will disperse outside the MPA's. Nowlis and Roberts (1998) modeled the potential of MPA to contribute to commercial fisheries. They found that the contribution depended significantly on the size of the MPA, and that a typical effect would be to reduce annual catch variation. Thus the larger the area of MPA relative to the fished area the greater would be the benefits to the fishery. Analysis of fish home ranges concludes that the larger the MPA the greater number of species of fish whose populations can be protected (Kramer and Chapman 1999). While it would be difficult to detect a commercial benefit from a small MPA, Nowlis and Roberts (1998) concluded that MPA were a viable fisheries management option and especially beneficial for species with slow population growth rates.

Attempts to control over-fishing through size limits and quotas have proven difficult to manage, and often result in significant mortality of 'by-catch'. It can also be more difficult to enforce partial fishery controls than simple bans. There is a strong argument that a network of MPA may be an essential tool for ensuring the sustainability of fish stocks. Indeed, regardless of the development of fishery no-take areas, the development of MPA will occur under the EU Habitats Directive.

Some types of fishing, notably bottom trawling and dredging damage the seabed and its marine life (e.g. Jones 1992, Kaiser & Spencer 1996, Macdonald *et al.* 1996, Collie & Escanero 1997, Lindeboom & de Groot 1998, Freese & Auster 1999, Prena 1999). The consequences of these impacts for fisheries are the subject of considerable research at present. Certainly there can be some negative impacts on seabed biodiversity, and nature conservation management seeks to protect some areas from trawling and dredging for this reason. Thus it is probable that at least trawling and dredging will be prohibited within some marine MPA designated as Special Areas of Conservation under the EU Habitats Directive. Current scientific advice is that 20 % of the oceans should be protected from fishing so as to better manage fish stocks (Bohnsack, Lubchenco, Davis, Roberts in Anon. 2000).

Conserving marine biodiversity

Conservation will promote sustainable, and minimise unsustainable, use of resources. Indicators are required for management to determine what level of use is sustainable. Prudent management will minimise pollution and habitat damage, and allow and monitor the recovery of impacted habitats and communities. Because contaminants can be dispersed widely in the sea, both by water movements and through the food chain, pollution control measures must be applied in all marine areas (as they are at present). However, resource harvesting that impacts on marine habitats and/or biodiversity may only need to be restricted within certain areas. It will also involve local people in coastal management, and identify priority areas and species for special protection.

The aim of nature conservation is to protect species from extinction through protecting their natural habitats and ecosystems. It takes millennia for species to evolve and once lost they are lost forever. While one can debate the current relative value of species to man and the environment, it is certain that with each extinction an option for the future use of biodiversity has been lost forever.

It is not possible to conserve biodiversity, especially in the sea, by managing it directly. Rather, the causes of biodiversity loss, namely human activities, must be managed. In the marine environment, this management requires direct actions, such as regulations, fishery controls, marine areas where certain activities are restricted, and pollution reduction. Indirect actions involve education, economic, social and political measures, based on current knowledge of marine ecology and ecosystem processes.

Nature reserve and species protection approaches can be effective in conserving biodiversity in the marine environment. However, they must be accompanied by wider pollution control measures. Additionally, because the population range and dispersion of most marine species is unknown, it is difficult to determine if marine populations in a locality are self-sustaining in the long term. Indeed, an increasing amount of empirical data indicates that marine larvae are not as widely dispersed by ocean currents as once believed (e.g. Lasserre 1992), such that "the paradigm of marine populations as open systems needs to be re-evaluated" (Cowen *et al*. 2000) (Myers 1994). Larvae of coastal species tend to have behaviours, such as vertical migrations, that aid their retention in their parental habitat (e.g. fish Cowen *et al*. 2000, Fisher *et al.* in press, gastropods Scheltema *et al*. 1996) or aid their dispersal from it (e.g. crabs Queiroya *et al*. 1997). Similarly, adult planktonic copeopods can use vertical migration behaviours in synchrony with the tide to reduce their dispersal from sea inlets (Kimmerer and McKinnon 1987). Because it is unlikely that marine protected areas (MPA) will encompass an area adequate for the sustainability of all species, habitats and species must also be protected outside MPA (Allison *et al.* 1998). One of the most effective and simplest to manage approaches to the conservation of natural resources and habitats is to restrict or ban certain human activities, such as types of commercial fishing, in designated areas (Box 9). Indeed fishery no-take areas are now realised as essential elements of fishery management, and the only effective way of protecting marine food webs and species vulnerable to by-catch mortality (e.g. Roberts 1997, Fogarty and Murawski 1998, Lauck *et al.* 1998). However, the size, number and management priorities for MPA will vary for the different species and habitats required to be protected (Schwartz 1999).

In parallel with protection of the wider environment and habitats, a key step in biodiversity management is to identify what is there, where it is, and provide comparative data for evaluation and prioritisation of conservation effort. Advice to management must recognise limitations of current knowledge but use all available data. Decisions must be based on knowledge and be supported by ecological theory. Conclusions should not be drawn from any lack of information. For example, it cannot be assumed that rarely recorded species are more widespread than data indicates without adequate surveillance.

There will always be uncertainties in predicting the effects of human activity on biodiversity. This is primarily because it is not possible to accurately predict local climate change beyond a few days, and climate is generally the over-riding factor in controlling species distributions. Thus both existing knowledge and theory must be used to manage biodiversity.

4.THE RESEARCH REQUIRED

Marine science in Ireland will need to support national and European policy through providing information and advice. For example, the main aim of the Habitats Directive of the European Communities (1992) is to "promote the maintenance of biodiversity". Article 18 requires Member States and the European Commission (EC) to "encourage the necessary research" to conserve (Article 2) and monitor (Article 11) biodiversity. The Directive notes that "the improvement of scientific and technical knowledge is essential for the implementation of this Directive; whereas it is consequently appropriate to encourage the necessary research and scientific work". Scientists will need to provide information and advice including

- descriptive baseline information on species' distribution, status and threats,
- methods to determine, avoid, and reduce impacts of fisheries, aquaculture, alien (exotic) species, genetically modified organisms, and other human activities on biodiversity,
- selection of indicators for monitoring and assessing the state of biodiversity,
- environmental assessment of spatial planning, development, and natural resource use, on biodiversity,
- new and improved techniques for using biodiversity resources,
- analysis of the costs, benefits and economic value of biodiversity,
- training and education at all levels, in particular identification of biodiversity.

All of this will require, (1) identification skills, (2) taxonomists and systematic experts to produce keys and, (3) new identification techniques. These taxonomic skills are essential for good practice and quality control in marine environmental research, monitoring and management. At present there are no designated positions in taxonomy in Ireland although some academics and museum staff do some work in this area.

International biodiversity research initiatives

Several European workshops have discussed biodiversity research needs, in 1993 (London, Anon. 1993), in 1994 (San Feliu de Guixols, Strömberg *et al.* 1995), in 1996 (Plymouth, Warwick *et al.* 1997), in 1997 (Stockholm, Larson & Catizzone 1997, Yerseke, Heip *et al.* 1998), in 1999 (Heip and Hummel 2000) and in 2000 (Azores). In 1998 an electronic conference on biodiversity research was held (Barcelona, Esteban *et al.* 1998). These meetings followed international workshops with a similar aim but composed of different scientists (Wilson 1988, Solbrig 1991, Peterson 1992, Solbrig *et al.* 1992, Grassle *et al.* 1991, Lubchenco 1995). The main outcomes of these meetings was to achieve a consensus amongst scientists about the research required, and the meetings stimulated mutually educational interactions and networking amongst scientists from different sub-disciplines and countries. The publications provide supporting arguments for biodiversity research and some usefully review the state of knowledge about biodiversity, including marine biodiversity (e.g. Ray 1988, Angel 1992). Many questions need to be addressed (Table 7) and they require a range of research approaches.

An international programme for research in biodiversity called 'Diversitas' has been established by IUBS, SCOPE, and UNESCO. This provides an international agenda applicable at the national and individual level, and has made marine biodiversity a priority. Its Core programme concerns (a) Origin, maintenance and loss, (b) Ecosystem function, (c) Inventory and classification, (d) Assessment and monitoring, and (e) Conservation, restoration and use, of biodiversity. Marine biodiversity is one of the four special target areas of research (STAR) in Diversitas. Such global programmes can give prestige to national initiatives which stimulate the availability of national funding.

A workshop sponsored by the European Union MAST (EU Marine Science and Technology) research programme reviewed marine biodiversity research in Europe, including Ireland, in 1996 (Warwick *et al.* 1997). It found most national effort focussed on describing marine biodiversity, producing inventories, systematics, monitoring and field surveys. However, there was very little co-ordination of this work at a national level and none at a European level. Because of this it was not clear where geographic and taxonomic gaps lay. Since then, the MAST programme has funded the Irish led 'European Register of Marine Species (web site at erms.biol.soton.ac.uk) project which produced a list of marine species in Europe, and identified gaps in expertise, identification guides, and taxonomic knowledge (Costello 2000). The 1996 workshop found there was less effort in the areas of relating biodiversity to ecosystem function, such as would lead to a better understanding of patterns and processes to support marine environmental management (including nature conservation and resource use). This requires special research projects of which there have been none at national or EU level.

The EU Fifth Framework Programme includes a strong element of marine biodiversity research. This research will probably involve Irish researchers, and its results will contribute to knowledge of benefit to Ireland. It would, thus, be appropriate that national research funding addresses aspects of marine biodiversity which would not receive EU funding where Ireland needs to improve its effort and which need to be implemented over longer time periods than the five year EU funding programmes. Examples include baseline surveys, modelling of local ecosystems and long term monitoring.

It is particularly important that management of the marine environment involves co-ordination and co-operation between countries. For Ireland, this clearly involves Northern Ireland, Wales, Isle of Man, England and Scotland, and also other countries which fish and do research in Irish waters. The Northern Ireland biodiversity strategy highlights the need for such co-operation (Northern Ireland Biodiversity Group 1998).

A framework for marine biodiversity research

There are several compatible scientific approaches to understanding and managing biodiversity. A valuable way of focusing end-user needs into research is to define the questions to be answered (Table 7). Thus more is known about biodiversity in stressed than natural ecosystem conditions. To address these questions, a range of approaches is necessary. The first approach is usually the <u>descriptive</u> which aims to determine what is where, how much of it is present (as abundance, biomass, or area), and if it is rare, special, or valuable. This may raise many fascinating questions but will not explain how these patterns are determined.

Much of what is known about marine biodiversity derives from species of commercial importance, and from situations where environmental conditions have impacted marine resources (e.g. pollution, algal toxicity, seafood contamination, fishery collapse). Thus research must include both ecosystems impacted and relatively unimpacted by human activities to gain an understanding of how man has altered ecosystems.

If descriptive studies are conducted in a standardised manner they lend themselves to an objective analysis of gaps in knowledge. This is an important tool because without <u>gap analysis</u> research will tend to follow the well-worn path. Researchers and their organisations typically lobby for more resources to extend what they already do. An objective assessment of gaps in the knowledge necessary for society to better protect and manage biodiversity may identify a need for research resources to be differently allocated.

The second approach is to analyse <u>patterns</u> in data collected, to see how biodiversity is arranged and linked in space and time. Common types of pattern analysis are monitoring changes in species abundance or distribution over time, and diet analysis to quantify trophic relationships. Data on biological variables, and biological and environmental variables, can be correlated to elucidate relationships between these factors and biodiversity. There is a need to look at different scales, both spatial (e.g. biome, seascape, habitat, microhabitat), temporal (e.g. hours, months, decades, centuries, millennia), and biological (e.g. molecular, individual, population, species, community) (Figure 6). In terrestrial ecosystems, ‘landscape ecology’ is now a well-established and popular topic because landscapes are practical management units. However, the utility of ‘seascape ecology’ as a tool in marine environmental research and management has not been studied.

A third approach is to relate patterns in biodiversity to ‘<u>ecosystem function’</u>. For example, changes in biodiversity with nutrient levels and physical processes in the environment. Biological processes can include species dispersal, growth and mortality. The patterns observed in biodiversity and between biodiversity and ecosystem processes will help make predictions over causes of current biodiversity. From past experience (replication in time) it is often possible to predict the impacts of human activity on biodiversity. However, <u>experimental studies</u> (the fourth approach) are needed to clarify cause and effect, and how ecosystem efficiency (function) is affected by biodiversity. These studies may involve in situ field experiments, mesocosms and aquarium studies. A recent review concluded that future marine ecological research should concentrate on addressing issues of spatial and temporal scale through the use of historical and palaeological data (100's – 1,000's years), long-term datasets, Geographical Information Systems, synthesis of existing data, experimental studies, and the use of marine nature reserves as study sites (Estes and Peterson 2000). Such a goal requires the range of descriptive, gap and pattern analysis, ecosystem and experimental approaches outlined above.

Table 7. Examples of questions that may be addressed by biodiversity research. For further suggestions see Angel (1992), Lasserre (1992), Heip *et al.* (1998), and Estes and Peterson (2000).

Conserving biodiversity

What marine species are most vulnerable to extinction?

What marine habitats and ecosystems are most disturbed by human activity?

What marine habitats and ecosystems are least likely to recover to their former state after human disturbance?

Is the removal of biological resources by fisheries damaging ecosystem function?

Is biodiversity decreasing in marine ecosystems?

What is a suitable size for marine management units and parks? How can these be defined?

Monitoring biodiversity

What are the most practical and representative indicators of marine biodiversity?

Biodiversity and society

How can we value marine biodiversity to link it with economic development?

Understanding biodiversity

What is the role of fragmentation and competition in the evolution of species?

What is the extent of biodiversity - how many species are there?

How closely connected are populations of different species around Ireland?

Are local populations of harvested species self-sustaining or dependant on recruitment from other areas?

Test hypotheses

(1) that physical (seabed, hydrography) heterogeneity is the most important factor determining composition (biodiversity) of benthic and planktonic species. If so, then biodiversity may be predicted by physical diversity, and thus allow management action to conserve biodiversity in the absence of comprehensive field data.

(2) that maximum summer temperature is second most important factor determining species composition and abundance in Ireland. If so, then the relative suitability of different areas for fish stocks and aquaculture may be better predicted based on sea temperature data.

Ecosystem function

Are more diverse ecosystems more efficient in cycling nutrients?

Is there any consistent relationship between biodiversity and ecosystem production?

What is a practical approach to defining an ecosystem area (e.g. local topography, hydrography, species composition) as a management unit?

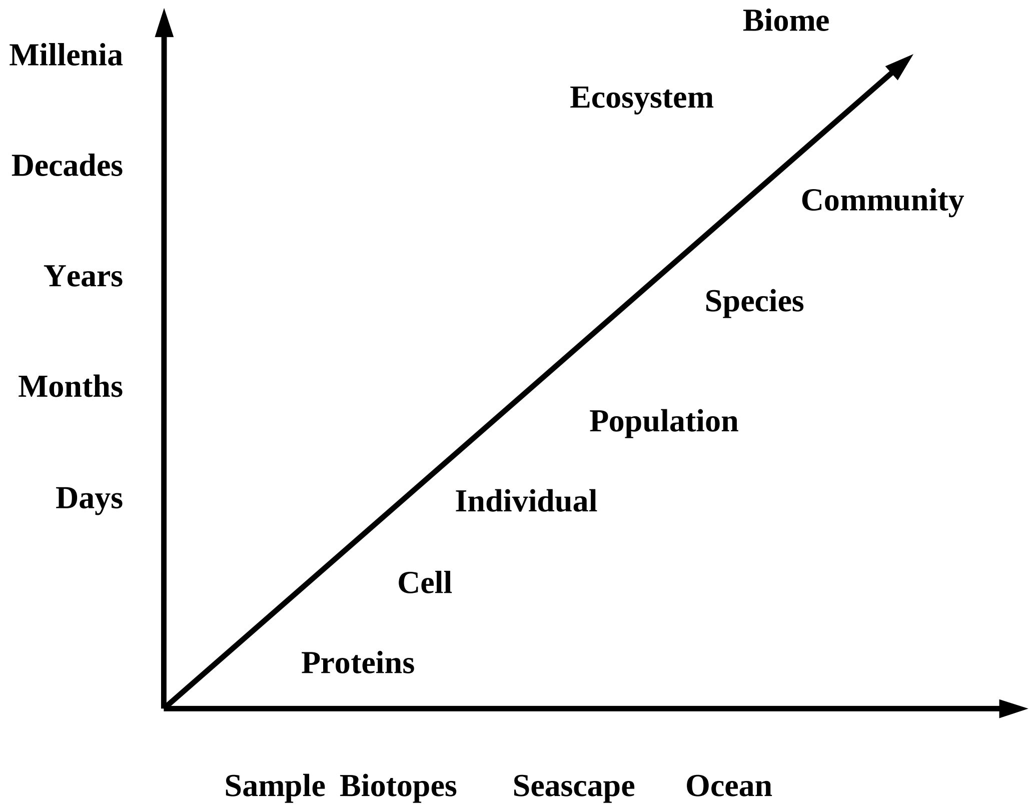

Figure 6. Different spatial, temporal and biological scales which need to be studied and linked in research into biodiversity.

Socio-economics

In practice it is more important to manage how mankind behaves and effects biodiversity, rather than to try to manipulate biodiversity. Thus, in parallel with the above research approaches, research is required to better integrate philosophy (e.g. Oksanen 1997), economics (e.g. Perrings *et al.* 1992, Swanson 1992, O'Neill 1997) and social problems (e.g. Wells 1992, Gadgil 1992), into the management of biodiversity.

A range of methods has been attempted to value aspects of the natural environment. These include placing a value on living resources and their environmental needs, what it would cost to treat waste artificially, what people would pay to protect biodiversity, the cost of replacing the resource, and the cost of relocating an industry which lost its resource (World Conservation Monitoring Centre 1992). The valuation of biodiversity can be a useful exercise for educating non-specialists in the role of biodiversity in human life. It may also provide a basis for the levying of environmental taxes to account for the impact of an activity on biodiversity. However, even in the absence of this information it is necessary to conserve biodiversity for the long-term benefit of society.

Infrastructure

All the above approaches require supporting infrastructure. This includes access to knowledge (e.g. libraries, Internet, conferences), state of the art training courses, and appropriate tools for researchers. Such tools include identification guides, availability of taxonomic expertise, biotope and habitat classification, standard species lists and nomenclature, statistical methods, conceptual and mathematical models, genetic techniques, and methods of measuring environmental variables. In all areas, quality control procedures are being increasingly demanded. While there are established standards for chemical analysis in laboratories, standards and protocols must also be developed for biological and ecological research. This must include both laboratory and field sampling and data handling methods.

Public education

Although productive seas with diverse habitats surround Ireland, and most people live near the coast, it is poorly understood by the public. This partly reflects its accessibility, but more its historically limited coverage in schools. A lack of public information and understanding can be a significant impediment to development. The foundation of government funded research is support from the public, industry, and politicians. This requires regular dialogue between, and mutual education of, the public, environmental managers and researchers. Even where scientists may have a skill to write in a popular style, it is unlikely that they will be able to get their material published in the popular press as easily as professional journalists with established contacts in the media. This dialogue will thus require communicators, such as science journalists, skilled in translating research into popular language and who have developed media outlets for this information.

5.THE STATE OF MARINE BIODIVERSITY RESEARCH IN IRELAND

Research in marine biodiversity in Ireland began in the 18th century. Towards the end of the 19th century several surveys on the marine fauna and flora were undertaken which resulted in descriptions of many benthic and planktonic species new to science. The fact that some of these species have not been found since reflects the limited basic survey work since. A survey of all the fauna and flora of the Clare Island area (Clew Bay, County Mayo, west of Ireland) conducted during the first decade of this century (Praeger 1915), produced the largest inventory of species for anywhere in the world at the time (Guiry 1997). Further research in the area is now being co-ordinated by the Royal Irish Academy, and the marine elements of this research concern the ecology of rocky seashores (Cabot 1999).

Since the 1950's certain geographical areas have received particular research attention. Pioneering field experiments were conducted in Lough Hyne in south-west Ireland by Kitching, Ebling and their colleagues to elucidate the roles of predation, grazing and water currents in determining the distribution of marine fauna and flora. There is now a bibliography of over 300 references on the Lough (Costello and Holmes 1991) making it one of the best studied localities in the world, and it is a statutory marine nature reserve since 1981. Initial interest in the Lough (since the 1880's) was stimulated by the richness of species, including several with a Lusitanian distribution. Further analyses suggest that the Lough's high number of species reflect both its variety of habitats within a small area (< 1 km^2), and that its high summer temperature facilitates breeding of populations which could not breed on the cooler coast outside the Lough (Costello and Myers 1991).

In the south-west corner of Ireland, Sherkin Island Marine Station has been monitoring phytoplankton, zooplankton, seashores and birds annually since the late 1970's. The station has worked with volunteers and experienced visiting scientists to conduct special studies on sponges, cetaceans, seals, underwater life, oysters, fish, anemones. It has amassed a considerable collection of reference specimens, photographs, library and produced many publications.

Reflecting the location of researchers nearby, the benthic and planktonic communities of Galway Bay and adjacent areas, and the benthic fauna of Dublin Bay have also received considerable attention (Kelly and Costello 1996). An unparalleled series of papers from University College Galway (now National University of Ireland, Galway) has addressed the biology of fish, plankton and benthic fauna and flora in Galway Bay and adjacent areas (Kelly and Costello 1996).

Research conducted

Most current marine biodiversity research in Ireland is descriptive, involving surveys of marine life for nature conservation (e.g. BioMar project, Costello 1995), and pre-development environmental assessment and monitoring. A major review of information on Ireland's marine environment has recently been published (Marine Institute 1999), and brings together both published and unpublished data on plankton, fisheries and benthic sea-life. There are annual government surveys of certain fish stocks for fisheries management, and of phytoplankton in areas with shellfish farms (Table 8). Records of cetaceans, birds and rare fish are well documented, but other taxa receive far less frequent attention (Table 8). The few studies reviewing other taxa depend on the personal interests of a few scientists rather than any co-ordinated approach to filling gaps in knowledge of the marine biodiversity in Ireland.

Table 8. An indication of baseline marine biodiversity studies in Ireland derived from the ED-MED database, literature, and personal communications. Studies include, environmental impact surveys (underlined) and annual government monitoring (*). CPR = Continuous Plankton Recorder, a system for collecting samples from ships of convenience run by the Alistair Hardy Foundation, Plymouth (Marine Institute 1999).

Subject of study	**Spatial**	**Spatial & temporal**	**Temporal**
Marine benthos	All coasts (BioMar)		
Subtidal marine macrobenthos	<u>Carnsore area</u> Dublin bay	<u>Kinsale Harbour</u> Galway Bay	
Intertidal macrobenthos	<u>Carnsore area</u> Clare Island area	Dublin Bay Lough Hyne Sherkin Island	<u>Bantry Bay</u>
Lagoon biota	All coasts (BioMar)	Ladys Is. Lake	
Plankton		All coasts (CPR)	
Zooplankton		Galway bay	
Phytoplankton	West to south coasts Cysts – all coasts *	Sherkin island area	Lough Hyne Bantry Bay* Carlingford Lough
Exotic species		All coasts *	
Cetacea		All coasts	
Fish stock surveys		All coasts *	
Fish communities	Lough Hyne		
Rare fish		All coast	
Amphipoda	All coast		
Mollusca	All coast		
Oligochaeta	Dublin Bay		
Macro-algae	All coast		
Genetics	*Asterina* species *Mytilus* and *Ostrea* species *Salmo* species		

The largest survey of the benthic marine fauna and flora of the Republic of Ireland, the BioMar-LIFE project (Costello 1995) was completed in 1997. A similar survey was completed for Northern Ireland in 1986 and both data sets have been published in electronic form on compact disc (Picton and Costello 1998). The benthic marine species and habitats at several sampling stations at each of about 650 subtidal and 200 intertidal sites were recorded. This descriptive information was used to identify areas of conservation importance in both countries and provided an empirical basis for a classification of inshore marine biotopes.

A weakness in Irish marine research is the rarity of experimental approaches and theoretical studies. The few such studies in the area of marine biodiversity were by PhD students and included UCC theses on the colonisation of experimental substrata in Lough Hyne by amphipods (M. J. Costello) and barnacles (R. O'Riordan), and meiofauna distribution in intertidal sediments (D. Murphy). An area only recently receiving attention in Ireland is the quantitative modelling of ecosystems, in which at least hydrographic conditions and nutrient dynamics are linked spatially and temporally. Nutrient modelling studies have been completed on Killary Harbour (Rodhouse and Roden 1987), Carlingford Lough (Ball *et al.* 1997, Ferreira *et al*. 1998) and Lough Hyne (Johnson *et al.* 1995, 2000), and are in progress for Cork and Wexford Harbours (Costello *et al.* in press).

In addition to marine biodiversity related research, several government agencies are involved in contaminant monitoring (Marine Institute 1999), and occasional environmental impact surveys also describe the biota of certain areas. Some work is funded through environmental surveys for proposed industrial development or following pollution incidents, and regular monthly monitoring of water quality is conducted at many salmon farms. The remainder of the work is supported by third level colleges and private sources (e.g. Sherkin Island, Lough Hyne seashore monitoring). The latter studies are motivated by the personal enthusiasm and interests of researchers, rather than by any national regulatory or research agenda.

There have been several surveys of expertise in environmental research in Ireland in the past few years. The most relevant to marine biodiversity is the ED-MED database which is published on diskette by the Irish Marine Data Centre, and includes volunteered information of data held by researchers based in Ireland. The Royal Irish Academy maintains a list of freshwater and marine hydrobiologists in Ireland.

There are several local peer-reviewed scientific periodicals suitable for the publication of marine biodiversity research results. These include Biology and Environment, Proceedings of the Royal Irish Academy, Bulletin of the Irish biogeographical Society, Irish Birds, Irish Fisheries Investigations Series, and The Irish Naturalists' Journal. In addition, a wider range of international journals accepts papers of international interest. Thus, there is no lack of suitable places to publish results.

Gaps in past research

As part of a survey of Irelands inshore subtidal and intertidal fauna and flora, a systematic review of the literature relevant to coastal ecology published over the past 200 years was undertaken (Kelly and Costello 1995, 1996). Entering the results in a well-structured format into a computerised database (Costello 1993) facilitated the analysis of gaps in past studies. Analyses of this data identified geographic and taxonomic gaps in knowledge, and described temporal trends. These reviews show that research effort does not tend to address imbalances in attention to geographic areas or taxonomic groups, but that these imbalances become exaggerated; i.e. there is an increasing number of studies in well-studied areas and on better known taxa over time. These reviews have not considered the relative contributions of individual papers, or whether the apparent imbalances are justified. To achieve a more balanced knowledge of Irelands biodiversity, then perhaps an increased proportion of effort should be directed to the less studied groups of species, to the north-west coastal area, and the offshore environment. A final assessment of priorities for marine biodiversity research needs to consider the apparent gaps in available information in relation to the potential resources and threats to marine biodiversity in Ireland.

Analysis of publications in the Irish Naturalists' journal found that over half (54-58%) of papers were consistently contributed by 12-21% of the authors, indicating the important contribution that a few scientists can make. The scientists who have contributed most papers related to the marine ecology of Ireland have been based in government institutes, third level colleges and commercial companies. Thus investment in further research should not discriminate between types of organisations, and should encourage both organisational and individual effort.

A list of the marine fauna and flora of Ireland and Britain has recently been revised (Howson and Picton 1997), and analysed for trends in the rate of discovery of species new to science (Table 4). However, what species were in Ireland was not distinguished. The results indicate that many marine species remain to be described from British and Irish waters, particularly from the smaller and less conspicuous taxa (Costello *et al.* 1996). Furthermore, they show that a few scientists can make a significant difference to the rate of discovery of new species, and suggest that developments in sampling methods and analytical techniques are less important than more survey and taxonomic effort. Considerable taxonomic research is needed to be able to name and identify the hundreds of undescribed species in Irish seas.

Most information on Ireland's deep-sea biodiversity was obtained about 100 years ago, with negligible national effort since (Box 7). However, this region has been impacted by bottom trawling for fish for some 20 years, and is now being surveyed intensively by geologists and explored for oil and gas reserves (Costello 1998). There has been no prior environmental assessment of the impacts of these fisheries or oil and gas exploration in the region, and until recently (Box 7), studies on Ireland's deep-sea biodiversity were limited to minor components of wider EU funded projects.

Facilities

In recent years, funding from the European Union has improved the facilities for research in marine biology, fisheries and aquaculture. For the first time in over 10 years, there has been a national programme for marine research. This has focused on resources of commercial importance and contributes incidentally to knowledge on marine biodiversity

Irish research has been almost entirely dependent on EU funding, as even the national research programme budget has been derived from EU sources. The Marine Institute has developed a framework for marine research and development in Ireland (Marine Institute 1998). This now needs to include research and development in marine biodiversity. This research and development plan will evolve and must be guaranteed funding over decades to maximise its impact on the economy and quality of life in Ireland. It should have the flexibility to fund large and small studies, cover salaries from the most senior researchers to students, and build on existing infrastructure. The major cost in biodiversity research is personnel. It is thus critical that funding to cover personnel matches the investment in equipment and facilities.

Limitations to research

In Ireland, available expertise rather than facilities, such as laboratories and research vessels, limit research output. There are only about 40 marine biologists employed full-time in Ireland (about half in temporary positions), amongst over 10 organisations. In the past, Ireland has not placed observers on many foreign research ships working in Irish waters (Symmons and Gardiner 1983). This state of affairs is a consequence of the lack of recognition of the importance of marine resources by the state until the 1990's. The reviews of published literature indicate that a few scientists can make significant advances in the study of marine biodiversity, such that is not necessarily the number of marine biologists, but the time that a few professional scientists can devote to a subject area that creates greatest productivity.

It is not reasonable to expect that Ireland will have expertise at an international level in every group of organisms. Indeed, all of Europe may only require a few experts in any one group. However, Ireland should have expertise in some groups and build on its strengths. If this expertise is where most work is needed and where European expertise is weak, then the international profile of Irish researchers will be higher. This will encourage international collaboration and funding. Appointments to academic and other government posts in Ireland should thus consider the strategic needs both locally, nationally and internationally. Ireland is a developed country with a strong economy. Its diplomatic profile internationally would be complimented by including funding of some research that is primarily of global and regional importance.

At present, the main limitation to marine biodiversity research in Ireland is that the relatively small number of researchers with capabilities in this area must focus their activities on national and EU funding. To encourage students to conduct projects which would train them in the basic scientific skills (e.g. taxonomy, sampling, field experimentation to test hypotheses) necessary for marine biodiversity studies, both national and EU funding needs to be targeted on marine biodiversity research, and authorities must recognise the necessity for training and standards in taxonomy and field sampling of marine life. Taxonomy is an essential part of quality control in marine research and management.

Although information may exist, it is not necessarily easily accessible in a form that it is usable for management and research. A national marine biodiversity database is long overdue. There are several models for the running of such a database, including a network of supporting databases accessed through a single web site, a client-server system in which parts of a single database are managed by authorised individuals located in different places, and a single centralised managed database. The latter option is the weakest because it does not develop a national team effort spirit, does not directly involve the participation of the experts, and is sensitive to staff availability (and Information Technology staff are particularly mobile at present). Elements of such a national biodiversity database already exist electronically, and key information in publications or other archives (e.g. National Museum) could be usefully digitised. Four groups of Irish researchers, two in universities and two in the private sector, led the establishment of the first register of the 30,000 marine species in Europe (the

European Register of Marine Species, www.erms.biol.soton.ac.uk) (Costello 2000). This is available in electronic format and was produced to provide a standard, quality controlled, species list for marine biodiversity management and research in Europe. Other relevant resources available or near completion include

- a digitised bathymetry of Irish coastal waters (at the Irish Marine Data Centre),
- digital photographs of the Irish coast (Marine Institute *et al*. 1999a, b),
- a digital coastline labelled with the main seashore habitats (Neilson and Costello 1999),
- an electronic bibliography of Irish marine publications published as a book by Kelly *et al.* (1997) and on compact disc by Picton and Costello (1998); and maintained by Ecological Consultancy Services Ltd (EcoServe),
- an interactive digital database of river quality in Ireland (http://www.epa.ie/rivermap/),
- a database of information on the distribution of macro-algae in Ireland (National University of Ireland, www.seaweed.ie),
- the BioMar –LIFE database of habitats and species at almost 900 sites around the coast (Picton and Costello 1998),
- digital maps of the littoral and sublittoral biotopes of the southern Irish Sea (Emblow *et al.* 1999),
- digital maps of nature conservation areas of Ireland (Duchas, www.heritagedata.ie),
- a hydrographic model of Irish coastal waters, and
- new surveys mapping the continental shelf margin.

Funding

The cost of managing marine biodiversity is already the responsibility of, and shared between, many government-funded bodies, departments, agencies, local authorities and educational institutions. It may be expected that some of the costs of implementing the Convention of Biological Diversity will be funded from the internal resources of these organisations because their work already includes aspects of biodiversity under different names. These organisations include the

- Department of Arts, Heritage, Culture and Gaeltacht (DAHCG),
- National Parks and Wildlife of DAHCG,
- Department of Marine and Natural Resources (DoMNR),
- Coastal Zone Unit of DoMNR
- Petroleum Affairs Division of DoMNR,
- Marine Institute,
- Bord Iascaigh Mhara,
- Central Fisheries Board,
- Regional Fisheries Boards,
- Department of the Environment and Local Government,
- Environmental Protection Agency,
- Department of Education,
- Third level educational institutes.
- Department of the Environment and Local Government

In addition, environmental non-governmental organisations and companies involved in fisheries, aquaculture, fish processing and marketing, marine technology, biotechnology, oil, gas and water abstraction (e.g. for cooling water), will be involved in activities affecting marine biodiversity. Their immediate costs may also be met to some extent from their own resources. However, the knowledge required by the government and public organisations to manage biodiversity will require independently funded research. This funding may be derived from a range of sources, including national exchequer, levies on industry, tax incentives, and European Union funding for research, environmental management and infrastructure. A more detailed analysis of how the contributions of different government and non-government organisations from existing resources would meet the requirements of the Convention of Biological Diversity is required to identify the new funds necessary.

Integration of the need to address biodiversity throughout marine research and regulatory activities would contribute to Ireland's legal obligations under the Convention on Biological Diversity and other agreements (e.g. OSPARCOM, Habitats Directive). Existing information concerning marine ecology in Ireland has been catalogued (Kelly *et al.* 1997) and reviewed (Marine Institute 1999). Before committing further funds to marine biodiversity research the potential for providing added value to existing activity should be explored. Although producing this added value will have a financial cost, this cost will be modest and yield a greater return on the existing efforts than presently occurs. For example, a review of current environmental monitoring may find that standard reporting and archiving procedures could form the foundation for a long-term monitoring programme with minimal additional cost. An increasing number of environmental impact studies (e.g. for aquaculture and foreshore licences) collect new information on the distribution of marine species around Ireland. While in principle this is publicly available information, in practice only a few copies of the reports are available and they are not archived. However, copies of EIS conducted as part of applications for Planning Permission are available at the ENFO library. It should be normal practice that a copy of all marine related EIS and similar reports are similarly archived in a library accessible to the public.

Co-ordination and planning could also provide for greater research in marine biodiversity. Research projects related to aspects of biodiversity, including aquaculture, fisheries, and environmental surveys, could more explicitly address the biodiversity research agendas (e.g. European Science Foundation, Diversitas, this report). A more detailed comparison of the recommendations of this report in relation to envisaged future national regulatory and funding actions, would allow the national obligations under the Convention on Biological Diversity to be most cost-effectively implemented.

6.CONCLUSIONS

This report provides an important contribution to the debate on the implementation of the Convention on Biological Diversity with respect to Ireland's marine environment. Despite the economic benefits arising from and legal obligations to protect marine biodiversity, its management is still compromised by insufficient information on what is there, how it changes in time, and why it changes in space and time. Answers to these questions are essential if marine ecosystem resources are to be utilised in a sustainable manner. Already most fisheries are at or exceeding their sustainable limits, an increasing proportion of the worlds population live on the coast, and pollution of the sea is continuing. There is an urgent need to improve understanding and develop theory on marine biodiversity to support management and conservation of marine biological resources.

Due to the pressures of human populations on coastal seas, marine biodiversity management in the coastal zone is urgently required for ecological, economic, moral and legal reasons. Because of this urgency, and the particularly poor state of knowledge of marine ecosystems, research must be focused to provide information to support coastal management. This needs to include a suite of multi-disciplinary approaches extending beyond traditional sciences to include economics, philosophy and social issues. Marine nature conservation benefits fisheries, aquaculture, tourism, ecosystem function and maintenance, and keeps options open for future generations to use and enjoy marine biodiversity. However, marine and coastal management cannot depend on paradigms based on findings in terrestrial or freshwater environments (Angel 1992). Managers must make decisions on fisheries, fish farms, waste discharges and other human activities within days to months, and cannot wait for long term studies related to each local situation. There will always be uncertainties in predictions and gaps in knowledge, but research will reduce both. New research into marine biodiversity must provide theories, models and supporting and baseline empirical data on which coastal management can base decisions and plans.

An essential requirement for the management of, and to underpin research in, marine biodiversity, is the compilation of facts and statistics on Ireland's marine environment. This information must be quantified spatially (i.e. map-linked), and maintained and disseminated electronically. Its quality will only be as good as the primary sources of information, so careful linking of the data to its sources is essential. The database does not have to be centralised but could be constituted of several independent databases accessed through a common web-site. Another model is for parts of a single database to be managed remotely by appropriate experts. Elements of such a marine database already exist or are in preparation as part of current Marine Institute managed research, and could be built on through a appropriately co-ordinated programme of research.

7.RECOMMENDATIONS

A range of recommendations covering issues of policy, management, monitoring and research are provided. Some must be implemented in order to fulfil obligations under the Convention on Biological Diversity. Most of these require little or no additional funding. They may be funded by a combination of government, European Union, and industry, sources. Some recommendations will be most effectively fulfilled through a partnership approach between state agencies, government departments, universities, Institutes of Technology, and the private sector.

The top priority is to develop a National Marine Biodiversity Resources Database. It is envisaged that this development will help prioritise some of the other recommendations, and will identify other work required. The other recommendations are not listed in any particular priority.

National Marine Biodiversity Resources Database

- Establish a regularly updated electronic
  - inventory of marine species in Ireland
  - bibliography of publications related to marine biodiversity in Ireland
  - database of the distribution, nomenclature, commercial and conservation status of marine species

  These facilities should be interconnected, via the World Wide Web, and have a system for their long-term maintenance.
- Develop a plan for the establishment and long-term maintenance of a national marine resources database that uses the best available scientific expertise and builds on existing data.
- Production of readily available electronic datasets (e. g. atlases, species databases, inventories, etc.) of Irelands marine and coastal environment and its biodiversity which will act as a form of ‘gap analysis’ and basis for additional layers of information.

Management

- Develop detailed Action Plans for management of biodiversity for each marine sector, including aquaculture, fisheries, tourism, hydrocarbon exploration and extraction, and transport.
- Establishment of a Working Group for marine biodiversity research to develop this report, advise on priorities and form a contribution to a national biodiversity committee.
- Inclusion of marine biodiversity in the national ICZM strategy and Research and Development programmes.
- Development of management strategies (e.g. codes of practice) for different sectors to conserve marine biodiversity.
- Involve public and private partnerships in marine biodiversity conservation.
- Provide national infrastructure to expand Irish biodiversity research in offshore and deep-sea environments.
- Establish more marine areas where human activity is controlled so as to protect marine biodiversity.

Environmental Impact Assessment

- To require assessment of impacts on biodiversity in marine developments, including aquaculture, new harvesting of natural resources (e.g. fisheries, gravel, sand, seaweed, oil, gas, coal, windfarms), dredging and spoil disposal, and construction works.
- To establish a publicly available archive for environmental reports conducted for offshore exploration and foreshore licences.

Marine Bioprospecting

- A national policy for the management of marine bioprospecting should be developed. This should encourage research and address the export of, and possible patents arising from, biological samples collected in Irish waters.
- Representative fully labelled samples of all biological materials collected in Irish waters by foreign research vessels should be lodged in a national archive, such as the National Museum.

Taxonomy
- Develop a quality control system for marine research and management that is based on best practice in taxonomy.
- Establish funding for training in identification skills, research in taxonomy, and methods for measuring marine biodiversity that will aid management.
- Develop the National Museum for archiving specimens and research in taxonomy related to marine biodiversity.

International activities
- Consider Ireland's responsibility as a developed country, and the benefits to the national skill pool and economy, of developing overseas marine research that would contribute to global as well as local issues.
- Marine biodiversity management should co-operate with neighbouring countries.

Monitoring
- Review of current marine monitoring activity in the public and private sectors, and instigation of a long-term programme to provide an integrated system for monitoring marine biodiversity and its environment.
- Identify how existing environmental monitoring datasets can be better used.
- Development of a system for the rapid and permanent availability of monitoring data for research and management.
- Implement measures to monitor and control the introduction and dispersal of exotic (alien) species.

Research
1. Support research to underpin management decisions, such as:
   - How marine biodiversity is generated and maintained,
   - Role of oceanographic factors in the dispersal of populations,
   - Potential of seascapes as units for managing marine areas.
2. Identify:
   - suite of techniques for monitoring and assessing marine biodiversity at genetic, species, biotope and ecosystem levels;
   - areas of significant marine biodiversity;
   - distribution of rare and endemic species;
   - biodiversity (species, genomes) of social, cultural, economic and ecological importance;
   - relationships between populations of species of commercial, ecological (e.g. indicator), and nature conservation importance so as to best design marine conservation areas and control harvesting strategies;
   - how connected or isolated are populations of important species around Ireland (e.g. are some areas sources of widely distributed stocks?)
   - the bio-prospecting potential of marine biodiversity in Irish seas;
   - the value, in social, cultural and economic terms, of marine biodiversity in Ireland;
   - the rates of recovery of marine biotopes from human impacts (e.g. under fish cages, trawling, dredging);
   - the economic and ecological benefits of Marine Protected Areas for fisheries and other resources.

Education, Fellowships and Training
- Establish a national system to support research by individual scientists in marine biodiversity. This should include post-doctoral fellowships, PhD studentships, and special awards for senior researchers in Ireland or overseas to take leave of absence (or sabbaticals) so as to conduct research on Ireland’s marine biodiversity. The possible need for training workshops in aspects of marine biodiversity should be noted.
- Review of educational resource needs at primary, secondary, tertiary and public levels in relation to marine biodiversity.

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Some useful web sites

European Research	http://
The European Register of Marine Species project (1998-2000)	erms.biol.soton.ac.uk
The European Science Foundation plan for marine biodiversity research (Heip *et al.* 1998)	www.esf.org/mpb/Marbio.html
The 1998 electronic conference on biodiversity research (Esteban *et al.* 1998)	www.gencat.es/mediamb/biodiv
EWGRB agenda for research into biodiversity (Larson & Catizzone 1997)	www.oden.se/~ewgrb
European Union	
European Community biodiversity strategy (EC 1998)	europa.eu.int:80/en/comm/dg11/docum/ 9842en.pdf
Habitats and Birds Directives	europa.eu.int/en/comm/dg11/home.html
European Environment Agency	www.eea.
European marine environment conventions	
International Council for the Exploration of the Seas (ICES)	www.ices.dk/
International Commission for the Scientific Exploration of the Mediterranean Sea	www.ciesm.org/
Helsinki Commission (Baltic Sea)	www.helcom.fi
Bucharest Convention on the Black Sea	www.wldelft.nl/projects/black-sis
OSPAR	www.ospar.org
International conventions	
Convention on Biological Diversity	www.biodiv.org
Jakarta Mandate	www.biodiv.org/jm
Bern Convention	www.coe.fr/org/legaltxt/104e/htm
World Heritage Convention	www.unesco.org/whc [or / mab]
Ramsar Convention	iucn.org/themes/ramsar
Bonn Convention on migratory species	unep.unep.org/unep/secretar/cms
Conservation of Arctic Fauna and Flora	www.grida.no/caff/index.htm
Other	
Duchas – The Heritage Service, data on protected areas (including marine SPA and SAC)	www.heritagedata.ie
Information on distribution of marine habitats and species in Britain and Ireland	www.jncc.gov.uk/mermaid
Marine Institute	www.marine.ie
EPA	www.epa.ie
Sherkin Island	homepage.eircom.net/~sherkinmarine
Coastal Zone Institute, University College Cork	www.ucc.ie/ucc/research/czi
UCG-seaweeds	seaweed.ucg.ie
Martin Ryan Institute, University College Galway	seaweed.ucg.ie/mri
The World Conservation Monitoring Centre	www.wcmc.org.uk/cis/