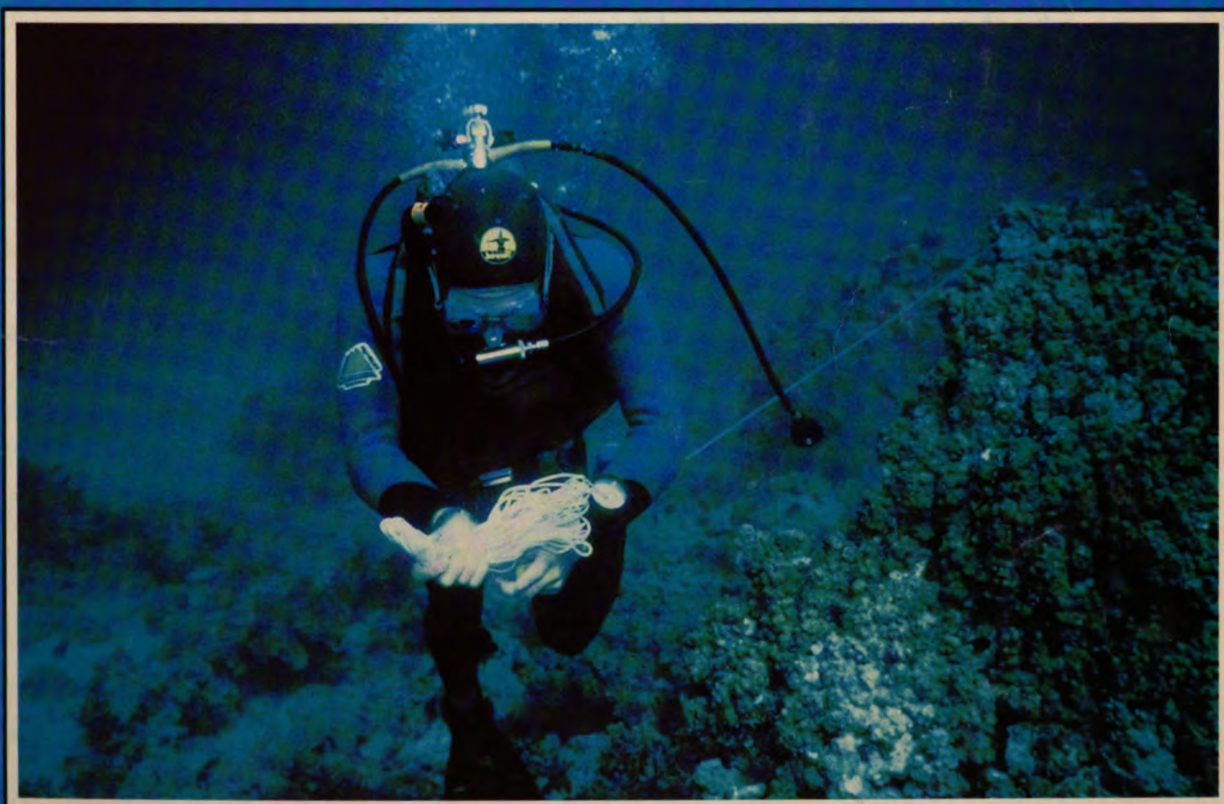
Protected Areas Programme
Marine and Coastal Areas Programme

The Science of Conservation in the Coastal Zone



IVth World Congress on National Parks and Protected Areas
Caracas, Venezuela

IUCN
The World Conservation Union

The Science of Conservation in the Coastal Zone

New insights on how to design, implement and monitor marine protected areas

WORLD CONGRESS ON PARKS AND PROTECTED AREAS

A World Congress on Parks and Protected Areas has been held each decade since 1962. The objective of the Congress process is to promote the development and most effective management of the world's natural habitats so they can make their optimal contribution to sustaining human society. The IVth World Congress, held in Caracas, Venezuela, 10-21 February 1992, aimed to reach out to influence numerous other sectors beyond those professionals directly concerned with protected areas. Management agencies, non-governmental conservation organisations, traditional people's groups, relevant industries and resource managers were brought together and involved to enhance the role of protected areas in sustaining society, under the theme "Parks for Life".

WWF - WORLD WIDE FUND FOR NATURE

WWF - World Wide Fund for Nature is the world's largest private international conservation organisation with 28 National Organisations around the world and over 5.2 million regular supporters. WWF aims to conserve nature and ecological processes by preseserving genetic, species and ecosystem diversity; by ensuring that the use of renewable natural resources is sustainable both now and in the longer term; and by promoting actions to reduce pollution and wasteful exploitation and consumption of resources and energy. WWF's marine work around the world highlights the conservation of overutilised fisheries and the systems that support them, the integration of management across scales appropriate to coastal and marine systems, the protection of species and populations threatened with extinction or extirpation, and the implementation of community-supported marine protected areas.

THE MARINE AND COASTAL AREAS PROGRAMME

IUCN's Marine and Coastal Areas Programme was established in 1985 to promote activities which demonstrate how conservation and development can reinforce each other in marine and coastal environments; conserve marine and coastal species and ecosystems; enhance awareness of marine and coastal conservation issues and management; and mobilise the global conservation community to work for marine and coastal conservation. The Marine Conservation and Development Reports are designed to provide access to a broad range of policy statements, guidelines, and activity reports relating to marine issues of interest to the conservation and development community.

The Science of Conservation in the Coastal Zone

New insights on how to design, implement and monitor marine protected areas

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Preface

Coastal zone planners and marine protected area managers face a daunting task in having to solve urgent conservation challenges without being able to rely on long term studies and the wisdom wrought by cumulative experiences. Integrated coastal zone management and marine protected area design are relatively young sciences -- thus conservation of marine ecosystems lags far behind that of terrestrial areas. Yet the needs are pressing, and ever more so each day.

We are now, it seems, beginning to pay the price for our past ignorance and incompetence. Nearshore and even open ocean systems are becoming badly degraded through overexploitation, indirect and point-source pollution, and habitat alteration or loss. The vital natural systems we once thought were limitless and resilient are now becoming functionally impaired and less productive. Our misuse of coastal ecosystems is a luxury we can no longer afford.

Science will help us meet these challenges, if we can harness it effectively. Doing so requires asking the right questions. Salient answers to those questions provide us the minimum information we need to move us in the direction of sustainable, long term use and enjoyment of the sea's bounty. Remembering that sustainability is a dynamic process, science will also help us monitor our progress and make the changes necessary to keep ecosystems productive and diverse and supportive of humans as times, needs, and environmental conditions change.

The ideas in this book were largely spawned by the marine protected area workshops held as part of the IVth World Congress on National Parks and Protected Areas held in Caracas, Venezuela, February 8-21, 1992. Organised by the IUCN - The World Conservation Union, the Congress brought together theoreticians and technicians, managers and researchers, academics and administrators. The Congress proved to be a valuable opportunity to exchange ideas and learn from others' successes and failures. Never before had so much energy been spent on assessing where we stand in marine protected area planning and how to improve our management efforts.

This document has been produced as a proceedings for the workshop entitled *The Science of Management in the Coastal Zones*. The workshop was the first of four at the Congress devoted entirely to marine protected areas. The text that follows is part advocacy, part technical reference. Although contributed papers draw on individual experiences from around the world, the examples used are not meant to be geographically comprehensive. Nor were attempts made to unify the writing styles of the authors. Nonetheless, this volume should whet the appetite of those wanting to know what progress has been made in marine conservation generally and marine protected areas more specifically. For further information, readers are encouraged to read the more formal and technical guidelines *Applying Science in the Establishment and Management of Marine Protected Areas* by Tundi Agardy and Simon Woodley, to be published by IUCN.

Part I
Overview of Science-Based Marine Protected Areas

Introduction

Why science-based marine protected areas are needed

All the earth is now impacted by humans. We have reached the point where it is virtually impossible to find any part of the world devoid of human impacts, any place lacking signs of the environmental stress we carelessly impose on the world that supports us. It appears the burgeoning human population is filling every nook and cranny of our little planet to the point of being near splitting at the seams. Even places we once thought of as being so remote as to be naturally outside our influence -- the great deep sea, the shores of furthest oceanic islands, the polar icecaps -- even here signs of degradation are visible. Some say these signs are the droplets of water presaging the impending burst of the allegorical dam; therefore we must take more serious notice of them.

Once the sea and its margins were viewed as infinitely large and endlessly productive. Marine biomes remain among our most vital, richest resources. Coastal areas the world over provide critical spawning, feeding, and nursery areas that support fisheries of inestimable worth to humankind. Coastal and estuarine areas are vital habitats for seabirds, migratory waterfowl, and countless endangered and threatened species. Coastal vegetation filters pollutants and plays a central role in maintaining ecological linkages between terrestrial and marine systems, as well as buffering the shoreline from cataclysmic storm damage and gradual erosion. Tourism and recreational use of coastal areas is a primary source of revenue for many coastal nations, while shipping, mariculture, and other sea-based industries contribute significantly to national economies. The rich tapestry of resources and ecological processes that oceans support are of undeniable import to humankind. Yet we treat our bays and estuaries, our coastal waters and open ocean areas, as if their misuse was our privilege -- carelessly hurling insults in the form of sewage, dumped debris, chemical pollutants, toxins, and overexploitation.

The edges of the rich tapestry have become tattered and faded. It may even be that the cumulative effect of our imposition of these many stresses has been to undermine the very health of these precious, live-supporting systems. Toxic algal blooms, fish kills, unprecedented marine mammal strandings, avian reproductive failure, crashes in fish populations, wide areas of eutrophication and anoxia -- all these signals point to something gone badly wrong. But despite our dependence on coastal and oceanic resources and processes, we have largely ignored the auspicious evidence of decline.

All coastal nations have the obligation to face the problem of coastal and open ocean degradation head-on. Collectively we have the resources, the scientific knowledge, and the infrastructure at our disposal to conserve marine resources and safeguard the processes that maintain them. Better marine conservation doesn't require huge expenditures or "Big Science" technologies -- it requires awareness, the harnessing of knowledge that we already have, and the building up of social and political will for concerted action.

Creating a litany of all the ways we negatively impact marine systems is not the best way to mobilise our energy and interest, yet we spend an inordinate amount of time doing just that. Instead, we might better benefit from practicing triage: identifying those problems needing immediate and coordinated attention. Medical waste washing ashore is not a priority issue, although in the western world the media may have lead the public to think otherwise. Eutrophication of coastal waters through agricultural run-off and sewage disposal is a priority problem. Similarly, non-point source toxic pollution, and subsequent accumulation of pollutants in the food chain, is a major concern.

Over-exploitation, brought about by our selfish attitude that the sea's bounty is free for the taking and aggravated by sectoral approaches to marine resource management, is not only depleting stocks but also appears to be causing gross imbalances in previously stable food webs as well as habitat disruption. When marine and coastal systems become heavily stressed, they seem predisposed to have their normal functioning dramatically altered by geographically large scale fluxes, such as that brought about by El Niño events or global climate change.

Thus the need to protect vital coastal ecosystems is great. But what should we do first, and where? How can we focus the conservation spotlight on the most salient problems in marine and coastal systems? Where should we plan our marine protected areas, design our coastal management regimes? These questions, though difficult to tackle, deserve attention. Typically we opt to take the easy way out, putting our parks and reserves not where they are most needed but, instead, where human pressures on resources are virtually non-existent.

Often, high species diversity is used to pinpoint so-called "hot-spots" for conservation. Although this lamentable technique has become most popular in prioritising terrestrial (especially tropical forest) conservation actions, it has recently entered the domain of marine conservation as well. For well-studied taxa there is no easier way to rank an area or habitat: the more species, the higher the area's status. Species are relatively easily quantified and species counts translate well into dramatic graphics. Species richness, a measure of the number of species present and the abundances of individuals, can be calculated by mathematical formulae that create the illusion that the question being asked has been sufficiently answered. But what is the pivotal question, after all? To be practical and effective, the central marine conservation question should be "what makes this area important from an ecological (systems) perspective, and how can its functional role be protected?" Then if triage becomes necessary, as it may well be, conservation and management can be targeted at areas where it will do the most good.

Thus high diversity areas may not necessarily be priority areas for protection from an ecological standpoint. This is particularly true in marine systems, where pockets of endemism are rare and habitats are functionally linked over wide distances. Some diversity-poor marine and coastal areas, such as saltmarshes, mangroves, and seagrass beds, may be more "important" in a functional sense because their productivity supports enormous food webs. And physical spaces that act as critical areas, if only seasonally, may fall off the tail end of diversity indices altogether. Such critical areas include courtship or spawning areas, migratory corridors, stopover points, and nursery areas.

The previous generation of marine protected areas followed the tendency to target areas of high diversity, or, at the very least, areas of relative pristineness. However, the days that afforded us the luxury of fencing off such living zoos (or, more appropriately, living aquaria) are now over. It is no longer a question of selecting the most appealing dish on the menu, it is now a question of abating hunger. We have moved into something of a crisis mode, and our new marine protected areas will have to target areas where conservation is needed most, not where conservation is the most attractive.

This may seem elementary and intuitively obvious. Yet what kinds of science can be used to make conservation more effective and where/when it should be applied is far from clear. There is to date little hard evidence showing how ecosystems respond to human pressures; in fact our knowledge about how components of any system interact is pathetically poor. We know a good deal more about how marine communities look than how they function. For practical reasons, we retain a bias for taking a structural, rather than functional, view of the world. Though it is possible to monitor the structure of ecological communities using such parameters as numbers of organisms, height and percent cover of plants, to indirectly ascertain ecosystem condition, this remains an insufficient proxy at best. And conservation plans still focus on maintaining structure, rather than safeguarding critical processes.

Whether or not you subscribe to the Gaia philosophy, it helps to think of the marine system as if it were an organism, with all of its intricately-linked living and non-living components contributing to the complex workings of a highly productive and resilient whole. As with a true organism, cumulative impacts stress the ability of systems to function normally, causing either declines in productivity or erratic wobbles in ecosystem linkages and balance. Some stresses are more problematic than others, and it is those impacts that affect the allegorical "vital organs" of the system that need most urgent attention. If use of resources is carefully thought out and we avoid undermining the function of those critical parts of the system, we will be one step closer to ensuring that resources will be there for future taking. This becomes the essence of "sustainability".

Once we have identified areas where marine protected area regimes are needed, how can they best be designed? First, we cannot and should not compartmentalise the seas, separating their management from our control of land use. Recognising natural linkages, it will be necessary to evaluate the ways we use our terrestrial resources, including freshwater, agricultural lands, industrial sites, and to assess how these ultimately impact oceanic productivity and health. At the same time, we must evaluate our direct use of marine resources and assess how exploitation affects the workings of the larger marine ecosystem. All of this requires looking at the big picture, synthesising what we know and promulgating management that truly aims us towards sustainability.

Identification of priority problems within the area of interest (the target system or area) is an important first step. But given limited time and resources, we are forced to recognise that we cannot protect everything at once. It is imperative to use knowledge of how coastal and marine ecosystems function, and what is most important to their continued functioning, to protect what we can as soon as we can. And where we haven't got the scientific information available to make such analyses, we must stand ready to incorporate new information with time and make our management plans flexible enough to accommodate change where change is necessary.

Marine protected areas, whether in the form of small marine parks or extensive multiple use areas, provide a valuable avenue for protecting critical areas quickly. A marine protected area gives us a geographic framework in which to make resource use sustainable, provides a tangible asset to local people and governments, forces the articulation of an institutional structure in which intelligent, forward thinking, and judicial development decisions can be made, and establishes a concrete set of reference points against which we can assess the condition of the marine environment and monitor the sociological, economic, and environmental success of our efforts. Thus marine protected areas may be the most important means at our disposable to begin turning the tide and stemming problems of marine and coastal degradation.

Central to efficient protected area planning is identifying where ecologically critical processes are concentrated in space and time. When these areas are well protected from both direct and indirect degradation, for example as core areas within a multiple use zoning plan, the marine system can continue to thrive, if relatively pristine, or begin its return to health and productivity, if degraded. Core and buffer zonation is useful in helping to protect the most vital processes while allowing optimal utilisation of resources to meet human needs.

In what may be a new era of marine conservation, novel perspectives in landscape and systems ecology provide the groundwork for zoning plans that will protect vital areas and move us closer to sustainability. Multiple use areas that are scientifically-based and realistically planned will allow continued exploitation of marine and coastal resources and accommodation of potential users without conflict.

The following pages elaborate how science can be harnessed to develop marine protected areas that are effective in conserving ecosystems and meeting human needs. Contributed papers address such topics as site selection, the question of scale, identifying core areas, and developing multiple use zoning plans. All these steps are vital to promoting better protected areas, and better protected areas themselves are crucial for bringing us closer to conservation of the seas, their margins, and the living planet as a whole.

The functions that marine protected areas serve

Multiple use, multi-objective marine protected areas are small scale models of the kind of integrated marine resource management we should be practicing on regional and even global scales. Marine protected areas help coordinate management activity so that it is optimally effective, and help satisfy human needs by ensuring renewable resources are sustainably used without undue user conflict. Well-planned marine protected areas will serve local communities as well as national economies.

To be truly effective, marine protected areas should address, or at least consider, four general conservation goals. First, where pressures to exploit resources are high, protected areas should espouse a management regime that is based on scientifically sound, rational definitions of what levels of use are truly sustainable. These sustainable use levels must be identified with the entire system in mind, not by taking the case of a single species at a time. Second, marine protected areas should devote special management attention to those components of the ecosystem (species or processes) that are highly threatened. Endangered biota such as endemic invertebrates, marine mammals, sea turtles, spawning stocks of over-exploited fishes, and coastal forests must be proffered special management attention. Third, protected areas should, through a zoning system, protect habitats that act as critical areas for the targeted ecosystem. Even low diversity areas with functional significance to the ecosystem should receive priority protection. Lastly, marine protected areas, since they do not occur in a vacuum but rather exist in the context of a wider matrix of differing management regimes, must tackle the problems of indirect degradation of the target ecosystem. They should act to focus scientific and political attention on the indirect degradation of target areas through point source pollution, uncontrolled run-off and poor watershed management, inconsistent coastal use outside the protected area, and global change.

Marine protected areas that have the support of local communities provide a necessary first step towards the attitude shift that is required if we are to avoid making a mess of the oceans. Education and awareness-raising are essential components of marine protected areas, as is scientific and management information exchange between areas. Most importantly, marine protected areas provide a mechanism for giving local people a sense of stewardship and control over their own futures; this in turn can only act to foster responsible attitudes towards the seas and coasts.

Why should marine protected area management be science-based?

Despite the fact that marine conservation utilising marine protected area planning and integrated management is in its infancy as a formal discipline, a dichotomy already exists between those who are pro-science and those who are anti-science. The division between factions results from misunderstanding. Extremists view the pro-science conservationists as nature-centrists, ignorant or unfeeling of human needs and desires. The anti-science group is more anthro-centric, fearing the focus on ecosystems will shift conservation towards traditional preservation and exclusion of even those people with legitimate rights to resources.

Science, however, is not a dogma but a tool. Used well, science can insure that marine and coastal ecosystems continue to provide human users with resources, space, and amenity. Appealing to rigorous scientific study to provide answers to the question "what levels of what kind of use are sustainable where?" does not diminish the central role that current and prospective human needs play in marine conservation today. But to be approaching conservation and natural resource management without science is like taking a desperate stab in the dark.

Science can help us in four general problem-solving areas: 1) to define true ecological boundaries of natural systems (eg. what effect will an activity in a specific locale have on the functioning of the system) which helps to identify the target area; 2) to help us understand how marine and coastal ecosystems work and therefore aid in identifying critical areas within the greater target area; 3) to allow development of zoning plans with buffers or analogues to manage resource use in a sustainable fashion; and 4) to permit us to monitor to see if our goals -- anthhrocentric and nature-centric -- are being met, while providing the information necessary to amend management if they are not.

As stated previously, science has most commonly served marine conservation in the identification of "hot spots" of biological diversity. Species-accounting is relatively easy (where basic data exist), and prioritisation by species richness remains one of the easiest ways to identify target areas. However, though high diversity areas may merit attention because they reflect conditions necessary for maintaining large numbers of potentially competing species in sympatry, they may not be most critical to the marine system as a whole. They are also often the places where conservation/management attention is least urgent.

Why, then, have scientists been coerced to use "hot spot" type approaches in order to help decision-makers identify areas where marine conservation is needed? Perhaps because such ranking is relatively easy to do. But even with caveats, biodiversity ranking is not wholly "scientific". Though the species label is easily applied and understood, and is thus the discriminating feature of choice for investigating biodiversity, diversity exists on all levels: demic, specific, generic, familial, and even at community and habitat levels.

Systems are more complex than meets the eye, and simplistic indices only gloss over this complexity. This may go without saying, but much of the scientific community has long resisted quantifying diversity at anything other than the species level. Furthermore, the spatial unit used in ranking areas according to their relative biodiversity importance is sometimes an "uncommon" denominator. In many marine systems the boundaries of biomes are blurred and the unit of area being sampled may not be clear. More of the ocean sampling space is out of reach as well, so bigger gaps exist in our understanding. Add to this the propensity of many classes of marine scientists to concentrate more fully on the genetic structure of populations (stock assessment, etc.), rather than on species differences, and species accounting becomes even less useful. However, a more open-minded view of what constitutes biodiversity will allow for a more diverse portfolio of conservation investment, and more chances for success.

If we loosen our grasp of the idea that biological importance means species number and distribution per unit area, and think instead about the roles ecological (including human) components have in the workings of natural systems, we can begin to think of efficacy of conservation investment. What ecosystems should be targeted, and what ecological processes need most to be protected? Diversity that is under direct threat should be protected from further onslaught. Endangered species should be protected by immediate conservation action, but so should endangered habitats (even if their species diversity is not particularly high) and endangered populations.

Even today, biodiversity conservation in many terrestrial and marine areas falls under the label of protectionism, that is the establishment of garrison reserves to fence in as many species as possible. In these efforts we attempt to guard recognised structure, with little regard to how that structure is maintained or how it might naturally change over time. No wonder the anthrocentrists are suspicious of scientifically-based priorities!

Process-oriented conservation allows us to harness science to protect critical processes so that human communities can continue to rely on vital ecosystems. Safeguarding the processes which maintain complex ecosystems and their immense variety of life forms is difficult. It requires more than surveillance (what is there): it requires understanding (why it is there). In some instances, where components of the ecosystem are closely linked, it may be possible to "fence in" enough of the critical processes that structural and process-oriented conservation is achieved simultaneously. In most cases, however, a lack of basic understanding about critical linkages means that sooner or later, structure-oriented conservation will buckle under extrinsic development pressure and the indirect but insidious side effects of anthropogenic activity.

In coastal and marine systems, scientists have begun to identify these critical or driving processes in the physical, geochemical, and biotic realms. Important features of the ecosystem which contribute to productivity, diversity, and resilience of systems include such things as upwelling, longshore and tidal fronts, warm and cold core rings, currents, freshwater input and mixing, nutrient loading and transport, atmospheric exchange, population recruitment, the existence of keystone species, symbiotic associations, and predator/prey relationships. This may seem like an impossibly wide spread of parameters for investigation, but our level of understanding is advanced enough to know that in certain systems, a few identifiable features may be the controlling factors. Limiting substantial negative impacts on those critical processes lessens the chance that we will impair the homeostatic capability of the system to maintain itself.

Work on the function of biodiversity in the context of community structure and eco-physiology is now beginning to take priority in some international scientific programs. The International Geosphere/Biosphere Program and IUBS/SCOPE have identified this as a priority area. Much important information can be derived from smaller scale efforts as well, and much could come from investment in these types of studies in high priority conservation areas. Even small steps forward in our understanding of linkages can facilitate leaps forward in conservation. For example, research concerning the linkages of tropical coastal critical habitats such as seagrass beds to coastal mangrove forests have been shown to effect better resource management and conservation in these biomes.

Many people claim that with the enormous gaps that exist in our knowledge about open ocean and coastal ecology, we cannot even begin to identify critical areas. However, no natural system is fully understood -- and incomplete knowledge does not justify inaction. This point is currently being debated in the context of prospective global warming, yet it is purposefully ignored in many discussions of natural resource management and conservation. We can never know enough, but basic and rudimentary knowledge is in most cases sufficient to develop a conservation approach that will be effective over the long term. Certainly the costs involved in establishing a network of multiple use protected areas are far less than the benefits derived from adhering to the precautionary principle and controlling our impacts before degradation becomes irreversible. The conservation mechanisms may need tailoring and refining as knowledge is gained, but the approach can be wholly scientific even when the knowledge is incomplete.

In the light of this uncertainty, a critical feature of any truly effective conservation measure is that both research and management components be flexible as new knowledge is gained. Some of this basic knowledge can and should be derived from long term and rigorous scientific study.

In some areas (topical as well as geographic), much knowledge may already exist "undiscovered" in the local culture. Wherever indigenous people live in close contact with natural systems, their beliefs and folklore may hold the key to understanding how natural processes work. Local knowledge is as least as important as scientific knowledge, and with diplomacy, may be more easily obtained. Despite this, many researchers dismiss local knowledge as being too "unscientific".

The science of marine protected area planning

Selecting and delimiting target areas

Without belaboring the point, simplistic indices of diversity, though currently popular, are not sufficient to select target areas for marine conservation activity. Areas rich in ecological processes, that in turn support extensively-linked coastal and marine systems, should be a top priority for selecting sites. And those areas that are most threatened by anthropogenic impacts require the most immediate attention. Marine protected area design and implementation in such high priority areas will advance the cause of marine conservation generally, by providing a management/education framework from which to scale up.

The following list of questions represents a generic set of considerations for targeting areas where marine conservation projects may have the best potential effectiveness to promote long term ecological sustainability:

1. Is the ecosystem in which conservation work is to be undertaken well understood?
2. Has the available information on resource distribution, abundance, and interlinkages been compiled?
3. Is the information presented in a way which can be assessed for conservation? Can it be mapped?
4. Is the area being protected a critical habitat for a threatened or endangered species?
5. Is the area representative of a threatened or rare habitat, that is otherwise under-represented in the global system of protected areas?
6. Does the area support identifiable ecologically critical areas? (eg. nutrient loading areas, high productivity areas, specialised feeding areas, breeding areas, areas important for courtship or other social functions, migration corridors, important habitat for keystone or other controlling species, areas which support populations of grazers, etc.)
7. Where critical areas have been identified are they adequately protected? Can they be demarcated to be better protected in the future?
8. Can critical areas be physically linked by "corridors"? Are seasonal variations adequately taken into account?
9. Is the habitat rich in endemic species? In endemic higher levels of taxa?
10. Is the area notable for supporting distinctive demes or other identifiable subsets of genetic diversity?
11. Are the ecological communities supported by the area particularly sensitive to disturbance? Especially resilient?

12. Is the area outstanding in its richness of native taxa, or its representation of a threatened biome (or rare refugia)?
13. Is the area outstanding for its "pristineness"?
14. Does the area have potential importance to allow monitoring of the health of larger-scale ecosystems? (ie. does it contain indicator species or habitats suitable for censusing?)
15. Has the importance of the habitat been framed in terms of regional significance or larger ecosystem function? Has the importance of the habitat been estimated in terms of economic or social value? If so, can conservation measures be directed at these non-market values?
16. Do local peoples/users recognise the "value" of the area or resource to be conserved?
17. Does the local community have previous exposure to conservation work or protected area planning, therefore being predisposed to understand and accept the principles of species and ecosystem protection?
18. Are local users of the resource politically empowered (ie. does the basis for long lasting stewardship exist)?
19. How dependent on a healthy, productive ecosystem are local communities and governments? Is the local economy resource-based?
20. What pressing problems, such as rampant poverty, hunger, political corruption, and disease, currently pre-empt conservation measures? Will a better-managed environment alleviate any of those problems, and on what time scale?

Furthermore, science is needed not only to evaluate the relative significance of areas (where to focus the conservation spotlight), but also to identify the ecological bounds of the system (adjusting the beam of the conservation spotlight so that the critical linkages are covered). This is a pivotal step towards effective conservation, for without identifying the limits of a natural system, even the most theoretically sound and socially acceptable management regimes will fall short of the mark. Even the strictest protection in one small corner of an ecological domain will do little to protect a coastal system in its entirety -- and without a comprehensive approach, ecosystem health and continued productivity cannot be assured.

Here the linkages between terrestrial and coastal/marine processes are central to harnessing the science effectively. Though our natural bias leads us to distinguish marine systems from those on land, the distinction has no footing in ecological reality. To illustrate how closely land and sea are linked one needs only to look back at how we have inadvertently degraded marine systems while undertaking some activity on land, sometimes far inland. Critical estuarine nursery areas, for instance, have often been dramatically impacted by diversion of freshwater from dams far upstream. Thus the beam of the spotlight will have to incorporate land use where vital terrestrial/marine linkages exist.

An oft-used example of how science can be used to delimit the target area for management and conservation is in determining what areas should be considered for inclusion in a coral reef management plan. Although the area to be protected is clearly definable and geographically fixed (ie. the boundaries of the coral reef itself have been charted), science is needed to determine the physico-biotic links between the reef and other habitats that support it. Such areas include seagrass beds, mangrove nursery areas, sea mounts and offshore pinnacles, that are often many kilometers from the reef itself.

Harnessing science to understand how ecosystems work and determine what needs to be protected most

Recognising that the creation of conventional parks will do little to abate directed over-exploitation and indirect but chronic degradation of vital coastal systems, marine planners have begun to develop principles for scientifically-based multiple use areas. These multiple use areas aim to protect those parts of the comprehensive coastal-marine ecosystem that are most ecologically critical -- targeting the vital organs, as it were. Two kind of basic questions need to be answered to provide the basis for such planning: 1) where and when critical processes such as nutrient loading, feeding, spawning and breeding, and migration are concentrated, and 2) which areas (and the ecological processes that they support) are most at risk from current or prospective human use.

As previously mentioned, conservative scientists might claim that our progress in this endeavor is hindered by a scientific understanding of coastal and marine systems that is incomplete and riddled with gaps. However even basic ecological studies can provide a solid starting point for coastal conservation, whether as a basis for biosphere reserves or any other form of multiple use area. Conservation needs worldwide dictate that we work with what we have, and that we make management as flexible and responsive to advances in scientific understanding as possible.

In some coastal and marine systems, scientists have identified the driving or limiting ecological processes in physical, geochemical, and biotic realms. Important features of the ecosystem which contribute to productivity, diversity, and resilience of systems relate to physical oceanography and hydrology, community ecology, and population dynamics. Again, though the task seems complex, a few controlling factors may be readily-identifiable. Regulating negative impacts on processes thought to be critical increases the probability that resource use will not impair the homeostatic capability of the system to maintain itself. Where this has been attempted for specific ecosystems, lessons can be extrapolated to provide guidance for other, less-studied areas.

A case study demonstrating this process is currently being developed in the Bijagos archipelago of Guinea Bissau, in West Africa. The archipelago is an immensely valuable, largely unexploited national asset. Forming the largest alluvial chain of islands in West Africa, the archipelago abuts and benefits from both major nutrient-loading river systems and an extensive continental shelf. The habitat, or beta, diversity of the area is significant, with a coastal system that follows a cline from mud/mangrove-dominated low islands inland to more topographic, beach-fringed islands offshore.

The archipelago is noteworthy in its biological richness for two important reasons: 1) endangered or rare species such as sea turtles, sea-going hippopotamus, migratory waders, manatee, and crocodiles are among the resident or visiting fauna, and 2) extremely productive mangrove and intertidal habitats support a vast profusion of marine species. Thus both diversity and productivity are high.

Only preliminary scientific surveys have been carried out in the archipelago, but some general principles can already be concluded. First, although nutrient loading is an important feature of this system, nutrients are probably not limiting (ie. nutrient availability in and of itself is probably not the basis underlying the structure of the food web and ecosystem). Second, certain physical features of the environment are distinctive and may be critically important for maintaining the diversity and productivity of this ecosystem. Such features include offshore rock reefs that may be important breeding areas for many fish species, areas of upwelling that act as concentrated feeding centres, seagrass beds and areas where oceanographic conditions allow high production of macroalgae, certain tidal canals that are both nutrient-rich and critical as pathways linking the marine system offshore with the more inshore coastal system, and land-sea interfaces such as stable beaches, productive and pristine mangrove canals.

Despite a paucity of scientific surveys in the archipelago, much of what is ecologically critical to keeping coastal and marine systems functioning (ie. what can be identified as "vital organs" in the process-oriented approach) can be deduced from simple oceanography. Hydrological flux is an important parameter for further study, as is localisation of precise areas where fish breed. A preliminary mapping of core sites targeting such critical processes can, of course, be upgraded and amended as further data are acquired.

It is not within the scope of this document to precisely outline the kinds of scientific parameters that should be investigated in order to derive the basic information necessary for targeting critical processes. However, the following physical features, inter alia, provide important clues to driving processes and their location within the conservation area:

1) Freshwater inputs, including riparian and groundwater, and hydrological cycling;

2) Tidal currents and mixing;

3) Oceanic frontal systems, incidence of warm or cold core rings, and upwelling;

4) Bottom topography or bathymetry (especially steep slope areas, pinnacles, offshore reef formations and channels); and

5) Areas of significant accretion or erosion.

Although physical processes play a dominant role in regulating ecosystem processes and determining ecological communities, biotic interactions are also important. Thus the following biological parameters may be critical:

1) Relative levels of primary productivity, including phytoplankton and macroalgae production;

2) Population dynamics of indicator species;

3) Food web structure, presence of keystone predators, and water column-benthic linkages;

4) Sources and sinks: recruitment dynamics and controlling factors; and

5) Migratory pathways or corridors.

Two other types of biological information are crucial: first, the inherent "sensitivity" of key ecological communities and second, the deterministic (eg. seasonal) and stochastic variability of the targeted ecosystem.

In addition to helping to articulate how the ecosystem functions and what is limiting in terms of ecological processes, scientific studies are also needed to determine the condition of the ecosystem to be protected. Here it is necessary to reiterate the point made in the introduction, that no ecosystem exists today devoid of human impacts. Before designing and implementing a management plan for a protected area, it will be necessary to know how and to what extent the system has deviated from its "normal", pristine condition. Environmental impact assessment is today a mature enough field, even in coastal applications, to provide useful tools for rapid assessments of environmental condition of an ecosystem or habitat.

Scientific information is critical not only to discern how an ecosystem functions and thus what is most important to protect, but also to determine what stands most threatened by human use and indirect impact. Such scientific research draws on information derived from the more basic studies mentioned above, used to elaborate how the ecosystem functions in both its pristine and "affected" states. Thus analyses of threat, though not independent from studies of ecosystem function and critical process identification, should be systematically undertaken once basic ecological knowledge is acquired. Analyses of threat must go beyond evaluating the current condition of the targeted ecosystem; they must be forward-looking, highlighting what is threatened today as well as what may be threatened tomorrow.

Developing ecologically-sustainable management schemes: Zoning core and buffer areas

This topic alone warrants a full book. However, since this document is not a set of technical guidelines but rather an overview of ideas, only general points will be made concerning zoning and subsequent management.

In a multiple use zoning plan, core area designations confer the strictest possible protection. This holds true whether the marine protected area is a multiple use park, an integrated coastal management system, or a biosphere reserve, and regardless of what the core zone is actually called. The use of core designations reflects the necessity to protect those ecological processes critical to maintaining the ecosystem. Thus core areas may be designated to protect critical seed stocks, critical areas for endangered or indicator species, especially productive areas, or areas with a suite of environmental conditions leading to many species living in sympatry (ie. high biodiversity).

If science is properly harnessed, core areas need not be very large -- and therefore, restrictions on human use of resources need not be imposed over wide areas. In fact, the better the scientific information about an ecosystem's resources and how they are maintained, the smaller core areas can be. To be effective, however, multiple use marine or coastal protected areas will have to utilise a system of multiple core areas.

Core designations may also be seasonal, or otherwise flexible. Though the spectre of multiple, seasonally-shifting core areas creates anxiety in the minds of planners and managers of marine protected areas, a comprehensive yet complex management system is not unfeasible. In part this is because long-standing users of the resource often have a solid understanding of the location and seasonality of critical processes, even if they don't articulate that understanding in scientific terms. Thus regulation of resource use can be predicated on users' well-developed sense of ecological function.

Buffer areas are needed to surround and protect cores. The buffer is an area of regulated use, in which resource exploitation is controlled specifically to protect identified core areas. Again, the decision about what to regulate and how to control impacts should draw from knowledge about ecophysiology and linkages. Use should not be prevented, but only controlled in order to safeguard critical processes.

Core and buffer systems may also be established in order to provide a framework for long term ecosystem study and monitoring. Thus the nature of the core will reflect the specific objectives that the marine protected area serves to meet. If the objectives relate to furthering scientific understanding by adding a locus to an established network of monitoring sites, for instance, the zoning plan will differ greatly from a plan that sets out to satisfy local community needs. The shape, size and number of cores is therefore not only a reflection of what has been deemed to be ecologically critical, but also a reflection of the goals of the marine protected area. In most cases, objectives will be diverse, and this will be reflected in a diversity of core "types" as well.

Determining sustainable levels of use

Though there is exhaustive coverage of this topic in the literature, it is again not within the scope of this document to review the state of the art for determining sustainable yields of natural resources. Three general points should be stressed, however. First, the determination of what level of resource use are ecologically and socially acceptable must not be undertaken with only a single stock or species in mind. Complicated ecosystem linkages pre-empt our ability to treat resources as independent entities. Second, attempts to determine what levels of use are sustainable should be grounded in scientific understanding of population dynamics, food web ecology, and genetics. Third, levels of permissible use must not be cast in stone: carrying capacities as well as human needs change with time. To accommodate these fluxes and create a management regime which is dynamic enough to be effective, a monitoring system will have to be put in place as soon as the protected area is established. The institutional framework for management of the protected area will have to be planned to be able to oversee not only the exploitation of resources but monitoring to ensure that conservation goals are indeed being met.

Using science to monitor conservation effectiveness

As stated earlier, a critical feature of any truly effective conservation measure is that both research and management components be flexible as new knowledge is gained from both long term and rigorous scientific study and, in some areas, "undiscovered" knowledge in the local culture. Local knowledge is as least as important as scientific knowledge, and may be easily obtained.

In addition to relying on continual inputs from local users of resources, managers of marine protected areas must be forward-looking enough to set an effective scientific monitoring programme in place at the time of implementation. As with the design of core zones, the precise parameters to be measured in post-implementation monitoring will differ not only with the type of ecosystem being protected, but also with the specific objectives that the reserve sets out to accomplish. When planning a monitoring and evaluation system, the feasibility of monitoring (including costs associated with the activity) must be taken into consideration.

Many papers have been published on the importance of monitoring and extensive technical guidelines have recently been developed as well. One common point in the majority of these publications is that the success of monitoring will be greatly increased if the system is designed according to Occam's razor: simplicity is best.

Expanding the pool of knowledge through information exchange

The IVth World Congress on National Parks and Protected Areas was not the first forum in which the gap between terrestrial park planning or resource management and that of marine systems was highlighted -- but it becomes more obvious with each and every major meeting of this type. One way that marine conservation can come up to speed, as it were, is to ensure that successes and failures are communicated as broadly as possible to facilitate learning from experience.

International protected area networks, including those served by the IUCN Commission on National Parks and Protected Areas and the UNESCO Biosphere Reserve Programme, play an important role in catalysing this information exchange. Informal mechanisms, such as exchanges between managers of different protected areas, can also facilitate learning. A great need also exists for the documentation of experience, via peer-reviewed scientific publications, as well as grey literature and public awareness campaigns. It is imperative that we articulate the need to protect the seas in a compelling way, and that we continue to reap the benefits from our accrued experience in the conservation of coastal and marine ecosystems.

Part II
Contributed Papers on Science-Based Marine Protected Areas

Scaling, disturbance, and dynamics: stability of benthic marine communities

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"The physical processes in the ocean and in the atmosphere have the same basic dynamics; however, the underlying processes have very different spatial and temporal scales. Cyclonic systems in the atmosphere have spatial scales of 1,000 km and last about a week, whereas the equivalent eddies in the ocean have spatial scales of 100 - 200 km but last for months to years. Weather systems are transitory relative to even short life history periods; most terrestrial species have some dependency on climate, but not weather. In short, the terrestrial animals endure changes brought by air but live apart from it except for short dispersal episodes. Aquatic systems, on the other hand live in the media, flow with it and are dominated by it. In the marine realm the water column sustains almost all life processes. The water column is an ecosystem of its own; it transports and even regenerates nutrients and oxygen and it is especially important in that it transports propagules."

Dayton, 1994

The implication of this for parks and reserves is that terrestrial systems are usually much more restricted in space; they are self contained within a given area responding only to climate. Marine systems on the other hand are absolutely locked into the larger aquatic milieu and they can never be effectively isolated from the larger system. Thus the core and buffer approach to managing terrestrial systems is practical with large enough cores but the blending of aquatic boundaries defies such a marine management scheme.

Benthic systems, however, while entirely dependant upon the aquatic milieu above them, have many parallels with terrestrial systems in terms of their spatial relationships. It is difficult to generalise benthic communities with regard to management for conservation. Clearly, it is important to understand the frequency and scale of natural disturbances as they relate to anthropogenic perturbations. Natural disturbances to benthic communities occur on a wide range of temporal and spatial scales, and there is no uniform response. The responses depend on size, intensity, and frequency of the disturbance as well as on the life history characteristics of the component populations. Individual species resist extinction by relying on good dispersal in space and/or persistence in time. Rough generalisations may also be made concerning fragility (resistance to and recoverability from perturbation) as well as sensitivity to anthropogenic impacts.

Temperate rocky intertidal communities compose a thin band along some shores, and in conservation sense, they are rare and fragile. They are characterised by frequent disturbances at relatively small scales. In many intertidal habitats the populations are recruitment limited and much of the space is unoccupied, while in algal turf communities a wide range of species seem not to be space limited but respond to various types of grazing pressure. In other cold temperate habitat exposed to heavy surf, the communities are functionally dominated by large algae. In some very space limited systems, the disturbances are important to the persistence of species; however, most species have the potential for considerable longevity. Patch persistence tends to be annual to, occasionally, decadal. The most serious anthropogenic disturbances to the intertidal habitat are collecting for food and recreation, and simply walking over and moving boulders.

Rocky subtidal communities are much different. Those on horizontal surfaces usually are dominated by macro-algae communities, and those on vertical surfaces or below the photic zone are dominated by encrusting communities of long-lived solitary or colonial filter feeding organisms. The algal communities are exposed to frequent disturbances at all scales. Sea urchin grazing is the most serious and long lasting disturbance to macro-algal populations. Encrusting macro-algae are very long lived and resistant to disturbances; however, they are easily overgrown by fleshy macro-algae which tend to be relatively short lived and disperse well. We can only speculate whether intense coastal fisheries have released the sea urchin populations which plague macro-algal communities worldwide. Other impacts include reduction in water quality and increased sedimentation.

There are many different types of encrusting communities, but in general disturbances are rare and the individuals are very long-lived (many decades to centuries) and often characterised by poor dispersal. Because many, but not all, species have relatively short dispersal ranges, this habitat could be protected, at least in part, by core and buffer schemes. The most serious anthropogenic disturbances probably related to over-fishing by intense coastal fisheries which have virtually eliminated entire classes of large fishes and invertebrates. Encrusting communities may or may not be susceptible to secondary effects of such fishing; we can only guess what effects the missing fishes and invertebrates may have had on these communities. Certainly at this point they are very vulnerable to physical disturbance and sedimentation from coastal construction.

Coral communities are exceptionally diverse. Their organisation emphasises biological habitats, often unpredictable recruitment, and many types of biotic interaction. They are impacted by natural disturbances at many scales including sea star attacks which can devastate hard corals, shifts in intensity of sea urchin grazing (population explosions or die offs), destruction from hurricanes, and bleaching. While their many types of regeneration make them relatively resilient to natural disturbance, they are sensitive to anthropogenic disturbance such eutrophication, sedimentation, over collecting, and destructive fishing techniques.

Soft bottom communities tend to be dominated by either deposit feeding or suspension feeding assemblages. Most of the habitat is of biological origin within the substratum and is thus vulnerable to disturbance. Small scale, usually predator related, disturbances tend to be frequent. The longevity of deposit feeders is variable; suspension feeders tend to be long-lived (decades) if they survive predation. Both have relatively long range dispersal. The most important anthropogenic disturbances relate to various types of fishing, especially trawl fishing. Incidental bycatch and ghost fishing of lost fishing debris are extremely pernicious problems. They differ from natural disturbance in intensity and scale; in many cases the animals have no escape. We can only guess what the habitats might have been before intensive worldwide fishing functionally eliminated entire communities of demersal fishes.

Polar habitats are very different, the Arctic basically is an enclosed sea with very large shallow shelf areas while the Antarctic is an island surrounded by narrow deep shelves and a strong circumpolar current. The Arctic benthos is characterised by clams and small crustacea with predation by walrus and bearded seals, demersal fishes and crabs the most important natural disturbance. The Antarctic benthos is dominated by filter feeders such as sponges and surface dwelling deposit feeders, with burrowing forms being relatively rare. Clams are inconspicuous, crabs are absent and there appears to be very little natural disturbance of the bottom. Fishery related problems are most conspicuous in the Arctic, but so far are not common in the Antarctic.

What can be learned about conservation of these habitats? Kenchington and Agardy argue the conservation management involves three main threats: 1) structural degradation of habitat; 2) effects on ecosystem processes; and 3) reduction of amenities. They suggest de-emphasis of structure because the system is so open; and they argue that "man-in" philosophy is ethically and practically superior to exclusionary "core" approaches. However many benthic systems are very vulnerable to structural damage and are not so open that they cannot profit from conservation, and in some cases a core and buffer system would at least help. These decisions absolutely depend upon some elementary understanding of local physical oceanographic processes.

The marine biosphere reserve (MBR) approach emphasises the logistic value of minimally disturbed managed reserves which serve as reference sites. That is, with education and motivation, marine conservation must include a large human presence. I am very much less optimistic about the human ability to manage resources that cannot be seen but which they hold in common: such optimism grossly underestimates the severity of existing over-fishing which is derived from the "commons" attitude and makes effective management almost impossible.

A different approach is offered in a report entitled *The potential of marine fishery reserves for reef fish management in the US southern Atlantic* prepared by Plan Development Team (PDT) (NOAA Technical Memorandum NMFS-SEFC-261, April 1990). This focuses on reef fish management, but has application to all fisheries. They identified several major problems:

1. Loss of potential recruitment because of insufficient spawning stock;
2. Increased probability of recruitment failure due to environmental uncertainty and shorter generation times;
3. Loss of genetic diversity within species resulting in less desirable stock;.
4. Massive over-fishing of many species;
5. Declines in abundance and average sizes of fish;
6. Loss of biotic genetic diversity;
7. Potential of disruptive reef fish community instability and permanent alterations;
8. Faster selection against desirable traits due to shorter generations.

The PDT suggest establishing marine fishery reserves (MFRs) which are completely protected, not even allowing catch and release. The idea is to protect older and larger fishes that are important to maintenance of original genetic stock (fisheries may frequently have a selective role). This protects critical spawning stock biomass, intra-specific genetic diversity, population age structure, recruitment supply, and ecosystem balance. Fishery reserves also provide insurance against management and recruitment failures, simplify enforcement, and have equitable impact among users. MFR sites with natural species equilibrium will allow study of age, growth and natural mortality and provide a basis for educational and scientific benefits.

The PDT recommend that 20% of the continental shelf be a reserve. The number, locations and size of the reserve must be calculated on a case by case basis, but they should include all the habitat types and the smallest boundary should be no less than 32km (20 miles).

The MBR and MFR concepts can be reconciled with only a minimal amount of physical oceanography. With sufficient oceanographic mixing, much could be gained with MBRs, but they do not do anything for genetic effects of heavy fishing. For that we still need reserves that are completely protected and large enough to maintain unfished breeding stocks.

Summarising, we have considered several types of benthic communities, some such as those in enclosed bays and wetlands are more vulnerable than others. Intertidal communities are very diverse; however, they are all vulnerable because they cover such limited areas, and worldwide they are massively altered by human attention. Enclosed bays are especially vulnerable to human disturbance and habitat destruction because they depend on diffusion of outside propagules. Subtidal rocky habitats are characterised by encrusting communities which are resistant to change but have very poor dispersal; thus they are very vulnerable to larger scale disturbances such as sedimentation. Coastal shelf communities have far reaching populations usually with dispersal potential and excellent recoverability from small scale disturbances; but they too are massively disturbed by coastal fisheries, especially trawl fisheries which destroy the habitat to the extent that recovery is difficult. Motile epibenthic or demersal species have been little studied by ecologists, but before being almost eliminated were probably important to the community. The main threats to the benthos are habitat destruction and over-fishing.

In summary, conservation priorities include aggressive control of fishing, complete protection of portions of rare habitats, identification and protection of particularly fragile or vulnerable habitats, and protection against exotic species. Suggestions for management of marine parks include consideration of the source of larvae; the water column and at least some basic oceanography. While a system of several small reserves can play an important role in conserving resources, appropriate fisheries management is essential and the developing large marine ecosystem concept is providing important new ideas towards this end.

Citation

Dayton, Paul K. 1994. Community Landscape: scale and stability in hard bottom marine communities. Chapter 10 (pp 289-332) in *Aquatic Ecology, scale, pattern and process.* Edited by P.S. Giller, A.G.Hildrew & D.G. Raffaelli, Blackwell Scientific Publicatons, Oxford.

Critical habitats and representative systems in marine environments: concepts and procedures

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Introduction

"We must renounce the image of ourselves as master of all we survey and accept the challenge as the only species apparently with capacity and imperative to maintain and manage....what constitute the life support systems of our planet"

Peter B. Bridgewater *et al.* (1992)

The long-term sustainment of biological diversity (or "biodiversity") is the primary goal for marine and estuarine protected areas (MEPAs). Unfortunately, as Angel (1991) has observed: "Like so many buzz-words, biodiversity has many shades of meaning and is often used to express vague and ill-thought-out concepts." This is partly a result of its marketing and partly due to the scientific complexity of biodiversity itself. As Solbrig (1991a) states: "Diversity is a fundamental property of every living system. Because biological systems are hierarchical, diversity manifests itself at every level of the biological hierarchy, from molecules to ecosystems." Thus, biodiversity has been defined at ecosystem, species, and genetic levels (Wilson & Peters, 1988). Equally important is a fourth level, that of functional diversity (Simpson, 1989, diCastri & Younès, 1990; Grassle *et al.*, 1991; Steele, 1991). Marine and coastal systems are extraordinarily diverse in all of these aspects (Ray & Grassle, 1991).

The challenge of understanding the nature and importance of biodiversity has resulted in a programme on ecosystem function of biodiversity called *"Diversitas"* initiated by the International Union of Biological Sciences (IUBS) and now in cooperation with the Scientific Committee for Problems of the Environment (SCOPE) and UNESCO. This programme considers ecosystem function as paramount owing to concern that: "Sustainability of ecosystems may be maintained in spite of species deletions up to a point, at which time there will systems degradation" (diCastri & Younès, 1990). A *Diversitas* subprogramme on "Marine Biodiversity and Ecosystem Function" (Grassle *et al.*, 1991; Lasserre *et al.*, 1994) has also been proposed with the same focus.

It falls upon protected area proponents to be more mindful of these scientific developments. Major reorientations in the way that marine protected areas are chosen, managed, and monitored will almost certainly result from the knowledge gained by scientists and by science as a whole. We are already observing that the ecosystem approach is resulting in a shift from the species-level of protection in individual protected areas to protection of regional life-support systems throughout a global network.

The conceptual basis

The Critical Habitat Concept

"Critical habitat" is largely a species-oriented concept and literally implies the existence of human-caused crisis or peril. The term apparently does not even appear in most biology and ecology texts, as it is equally concerned with social values, scientific knowledge, and management. The application of the concept is mostly applied to a few well-studied, high-profile, endangered species. But even for them, serious problems are evident (Rohlf, 1991).

Ray (1976) defined "critical marine habitat" to mean "those identifiable areas which are vital to the survival of a marine species, at some phase in its life cycle, or of a marine habitat, community of ecosystem because of the ecological processes that occur within it." This all-inclusive statement may have been satisfactory for its time, but now approaches old age. The other side of the coin is expressed by the null hypothesis: *There are marine areas that are not critical to species' survival and to ecosystem sustainability.* If such areas can be shown to exist, we will know where the critical areas are!

Six observations shed light on the problems of selecting critical areas, or "hot spots" as they are often called, for special priority (Ray, 1992):

* No environments are devoid of species dependency;

* Every species requires a mosaic of habitats for its continued existence;

* Most species are naturally rare;

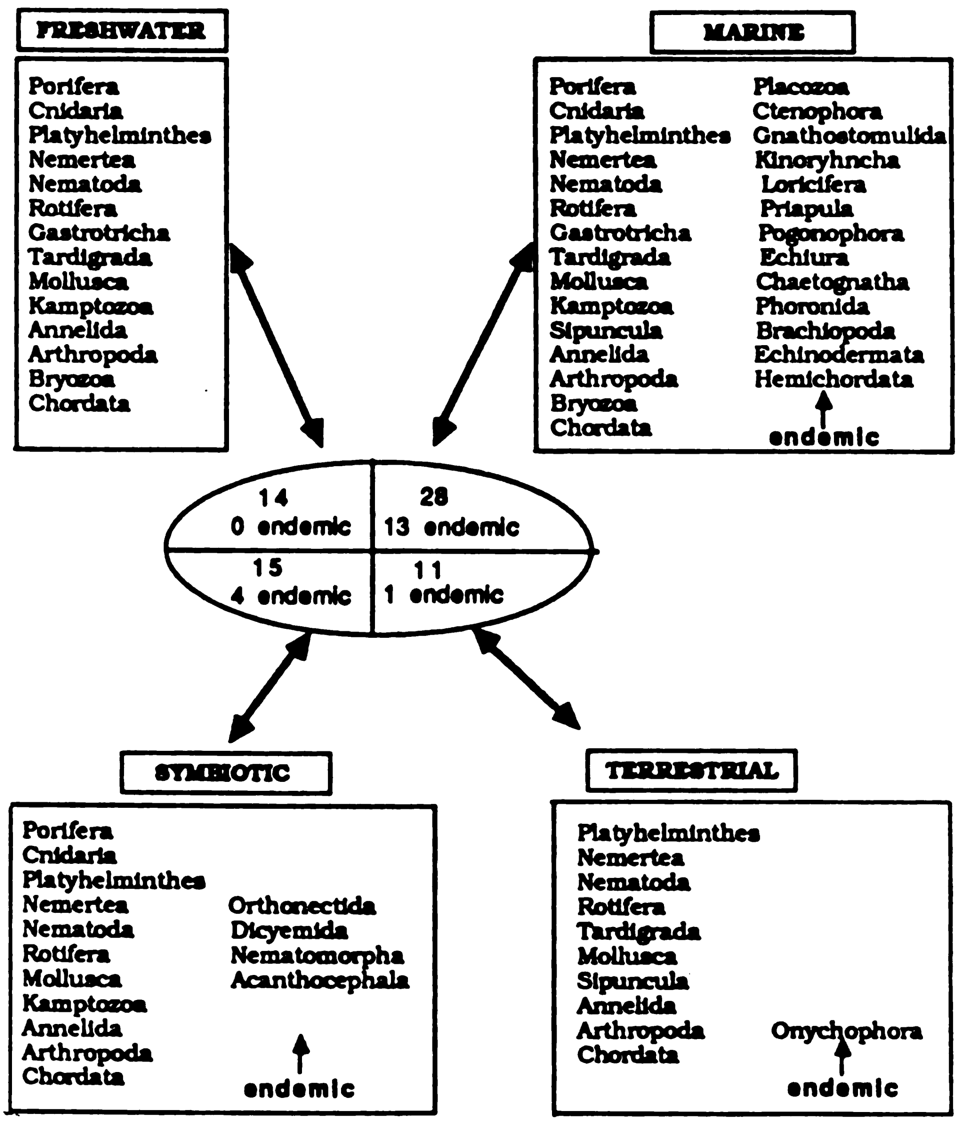
* Species distribution and life histories are largely unknown;

* Cause effect relationships of human-caused *vs* "natural" threats remain highly uncertain;

* Coastal and marine ecosystems are especially dynamic and non-linear.

Figure 1 illustrates the fact that the marine realm is most diverse in animal phyla, therefore in animal life forms, by a significant margin. Every portion of the seas is occupied by a wide variety of taxa, and a mosaic of habitats at varying scales is required for the continued existence of most species. Furthermore, whether or not species are endangered or naturally rare mostly

Figure 1.
Distribution of Animal Phyla by Realm (Grassle *et al.*, 1991)



results from our ignorance of species' natural histories and variations in their relative abundances. Also, it seems clear that determining what is "critical" requires understanding social and scientific factors, understood in the context of the non-linear dynamics of marine systems -- a very large order!

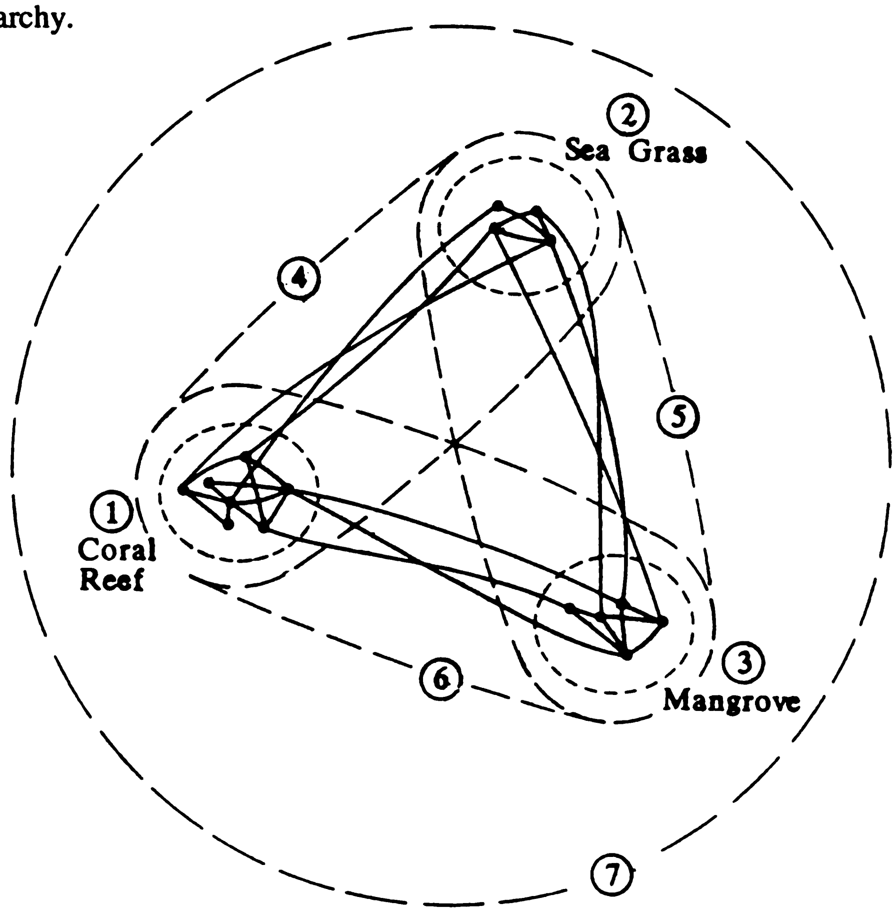
These observations, taken together, strongly suggest that selective management for particular species would inevitably lead to the disadvantage of other, non-selected ones. Hence, the preservation of "critical habitat" or "hot spots" of high diversity or endemism, or for selected (usually charismatic!) species, is not an optimal approach for biodiversity conservation. We do not suggest dropping the "critical habitat" approach for well known and clearly endangered species (eg. nesting beaches for sea turtles), but we do strongly suggest that conservation science become reoriented towards identifying land- and seascape mosaics and understanding their dynamics over large, regional scales (Simpson, 1989).

The Land- and Seascape Concept

Rather than become entangled with what is critical and what is not, we suggest a different approach for the sustainment of biological diversity, one that is based on ecological theory and the emerging science of landscape ecology. Ogden (1992) suggests: "Conservation in the sea must be geographically scaled to mosaics of ecosystems, defined by ocean processes and distributions of biological diversity". The recognition of the spatial and temporal scales of these mosaics of ecosystems, their structure and function, and the human impacts on them is essential for MEPA establishment and management.

Reichle *et al.* (1975) define a system as "a complex of interacting subsystems which persists through time due to the interaction of its components. The system possesses a definable organization, temporal continuity, and functional properties which can be viewed as distinctive to the system rather than to its components." Ecosystems are recognised to be complex, hierarchical, non-linear entities that are geographically bounded by gradients called "ecotones" (diCastri & Hanson, 1992). Hence, one must view ecosystems as nested within varying time and space scales (Bailey 1984; O'Neill *et al.*, 1986; Urban *et al.*, 1987). Figure 2 gives an example.

Figure 2.
Hierarchical Organisation of Inshore, Tropical Ecosystems
The shaded areas are coral reef, seagrass, and mangrove ecosystems. The dots represent species and the solid lines represent food webs. The circled numbers indicate different relationships among species for each of seven communities that share these ecosystems. Note the three levels of the hierarchy.



The relationship of biological diversity to ecosystem structure and function is complex and poorly understood, as illustrated by the null hypotheses posed by Solbrig (1991b). For example:

* habitat fragmentation has no effect on extinction probability;
* spatial heterogeneity of the regional land-seascape has no effect on the number of functional types or coexisting species in a community; and
* removals and/or additions of functional groups that produce changes in spatial configuration of land- and seascape elements will have no significant effect on marine ecosystems functional properties over a range of time and space scales.

Testing of such hypotheses for management of protected areas is obviously of immense significance. Of equal importance is the examination of methods and the criteria to be used for selection of MEPAs.

Towards a representative system

Ray and McCormick-Ray (1992) present a strategy for selecting a representative system of MEPAs. The strategy is summarised as follows:

The Vision

The vision for conservation of coastal and oceanic systems and their resources should lead to a holistic, ecosystem-based approach, which links local concerns with national and international perspectives in a coordinated system of cooperation. Three predominant goals of this vision are interwoven:

* Conservation of biological diversity at all levels, from species to ecosystems, and to land- and seascapes;
* Sustainability of resource use and maintenance of ecosystem integrity; and
* Assessing effects of environmental change through research and monitoring.

It is significant that the Sustainable Biosphere initiative, initiated by the Ecological Society of America (Lubchenco *et al.*, 1991) has almost identical goals. Meeting these goals places the burden on both science and management to be more explicit and interactive. Otherwise, the societal dilemma over resource use will continue.

Guidelines

Ecologically sustainable use is a fundamental operating principle for MEPAs. But what is meant by this? How can human use be matched in time and space with ecosystem structure and function? How many MEPAs, and of what dimensions, are required to protect biological diversity? How may ecological or resource changes be measured so that the degree of impact becomes known and human uses modified?

Many sets of principles, guidelines, and criteria already exist for MEPAs (eg. Ray, 1976; IUCN, 1981; Ray *et al.*, 1981; Salm & Clark, 1984, Kenchington, 1990; Kelleher & Kenchington, 1992). However, these guidelines are principally devoted to selection, planning, and management. They are not scientifically sufficient to address present needs for meeting the forementioned goals.

Table 1 lists guidelines for consideration in establishing MEPAs, as suggested for Australia by Ray and McCormick-Ray (1992). These guidelines place increased emphasis on scientific procedures. The first guideline is clearly to define objectives that are ecologically and socially attainable such as sustainable fisheries or protection of a habitat. The objective is defined operationally, with measurable endpoints; that is, identifying and monitoring key indicators (while recognising that some important values -- eg. aesthetic, wilderness -- are difficult, if not impossible, to quantify) requires clarity about the desired state to be attained. Only after objectives have been clearly identified should wide public support be sought, possibly to be modified during a participatory process.

Table 1.
Guidelines for Marine and Estuarine Protected Areas (MEPAs)

Guideline 1	Define operational objectives
Guideline 2	Gain public support
Guideline 3	Apply scientific procedures
Guideline 4	Develop a central information system
Guideline 5	Represent a diversity of the land/seascape
Guideline 6	Emphasise land-sea interactions
Guideline 7	Relate objectives to appropriate scale
Guideline 8	Focus on ecosystem processes
Guideline 9	Set MEPAs in a regional context
Guideline 10	Attain a national network

As an example, boundary delineation depends on understanding the structure and function of the ecosystems that are specifically related to the operational objective(s) for which the MEPA is proposed. Most important for achieving sustainability is that MEPAs be ecologically delineated, with scientifically defensible boundaries. Furthermore, management strategies should be based on the understanding of biological and ecological properties and on the extent and effect of natural and human perturbations.

Special tools are required to facilitate boundary delineation, scientific analysis, and management planning. We suggest that a scientifically designated geographic information system (GIS) be the primary tool. ERIN (1990) describes a GIS as: "a specialised system for data management... designed for the entry, analysis, management, and display of data commonly found on maps....[providing]....three main advantages. First, a digital system is often less expensive and more efficient that doing work by hand; second, a GIS is able to provide accurate and fast delivery of information to users; and third, a GIS is able to provide immediate access to analytical, expert-system, and decision support facilities."

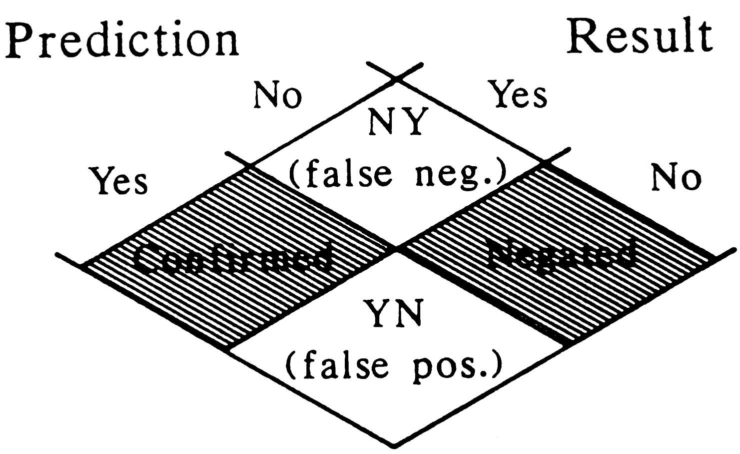
A caveat about the use of GIS is that interpretation requires expertise. At the decision-making stage, close interaction between the expert and the public or policy-maker is essential. Mackey (1990) states: "One view of GIS is that they are simply digital cartographic systems. This assumes that all the environmental factors we're interested in have been mapped and that we can use computers to digitise and automatically '*overlay*' them. While this approach is useful for some portfolio applications, it is simply not a feasible methodology for many environmental and ecological problems." That is, a GIS should never become simply a self-fulfilling planning tool.

Need for Strategic Assessment: Developing the Representative System

A fundamental dilemma for society resides in choice of values and the setting of priorities for our common future. The public is clearly ambivalent about setting priorities. Great environmental concern may be shown on the one hand and preference for the benefits of an industrial society on the other. This ambivalence is solvable only insofar as the public at large clearly understands the issues involved and the basis on which management decisions are made.

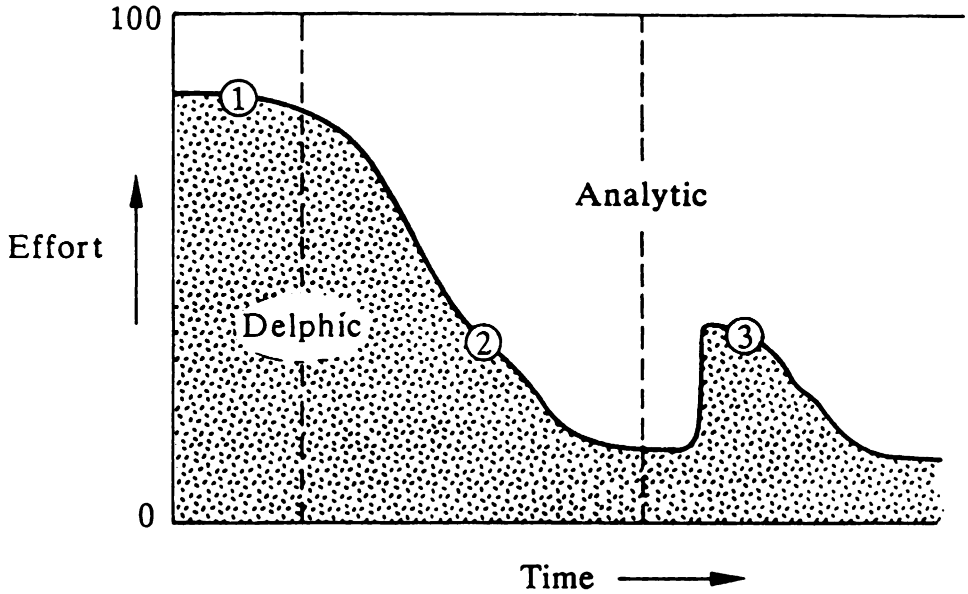
MEPA management plans may identify attributes that society values that are at risk, but they rarely present a clear, analytical basis for making management decisions. Thus, they may appear to deprive the public of its perceived rights of use. This is largely because much MEPA planning is still dominated by so-called "Delphic" procedures. This approach is expedient and may use the best professional advice, but it is usually based on consensus and often confuses social and scientific issues. Hence, this approach may be characterised by obscurity or ambiguity, with difficulty in distinguishing between what is assumed and what may be confirmed (figure 3).

Figure 3.
Prediction Dilemmas -- the False Positive and False Negative



On the other hand, an analytic procedure derived from an adequate information-base by experts can usually solve this problem. In practise, however, the choice is not between Delphic and analytic procedures. Rather, the two should be used in parallel, with feedback mechanisms built in. Initially, the emphasis will be on judgmental procedures, but over time, analytic procedures will predominate (figure 4).

Figure 4.
Delphic and Analytic Procedures
The first phase (1) involves expert judgement; the second (2) requires information generation and testing, during which analytic procedures dominate; the third (3) involves new concept formulation and analysis, and is an iteration of (1) and (2), making possible the tracking of MEPA management as a "moving target".



Strategic assessment procedures provide mechanisms for integrating collaboration among scientists, managers, and the public, and for deriving information from raw data. These procedures allow distinctions to be made between the need for scientific clarity about how ecological units and candidate sites may be identified and the need for selection of sites based on social value judgements and human impacts. Thus, site *identification* is largely a scientific process; site *selection* is mostly derived from social and pragmatic reasoning. If these two processes are not made distinct, confusion and bias will inevitably result, to the detriment of management of the area and resources to be protected. Procedures outlined in Kelleher and Kenchington (1992) bear some of these problems of mixing social and scientific information and identification and selection procedures.

Strategic assessment also provides a framework for reviewing existing sites and identifying future needs. This includes review of existing MEPAs in the context of their operational objectives. Gaps may be identified, representativeness assessed, and the steps needed for obtaining a national or international system outlined.

Steps in the Strategic Assessment Process (figure 5) can only briefly be reviewed here. They include:

Step 1: Preliminary Site Assessment

This step reviews and briefly assesses existing MEPAs with reference to the national and international goals of protecting biological diversity, achieving sustainability, and monitoring environmental change. It offers suggestions for addressing gaps and for identifying new MEPA sites.

Figure 5.
Steps in Strategic Assessment

Steps:	I Preliminary site assessment	II Concept development	III Refinement and iteration
Tasks:	1. refine the classification	GIS development	
	2. Characterise existing MEPAs	Characterisation of environments	Research and monitoring
	3. Evaluate MEPA representativeness	Identification of the network	
	4. Preliminary additional site list	Enhance public acceptance	
Products:	Proposed representative system (short-term)	Identified representative system (long-term)	Information for improved management

Task 1: Refine the Biogeographical Classification. It is assumed here that key attributes of a candidate region for MEPA development have been identified. Theme maps accompanied by listings of dominant attributes of coastal-marine ecosystems now need to be assembled. The assumption is made that a limited number of key attributes can provide considerable insight into the nature (both structure and function) of ecosystems, as appropriate for MEPA implementation. For assessment of adequate representation of dominant habitat types and dominant species in prospective MEPAs, a hierarchical, environmental classification is also needed.

Task 2: Characterise Existing MEPAs. Existing MEPAs may now be assessed by assembling data on the "presence-absence" of defining attributes determined in *Task 1* and which may include both physical features and dominant species and habitats.

Task 3: Evaluate MEPA Representativeness. The refined classification *(Task 1)* and the data for existing MEPAs *(Task 2)* may now be compared. A simple check-list will reveal presence-absence of attributes at a local, regional, and national scales. Thus "representativeness" is both defined and mapped. However, detailed evaluation is left for Step 2.

Task 4: Preliminary Additional Site List. Attributes included in the classification, but not included in existing MEPAs will suggest the need to identify candidates for meeting additional needs. New sites with these attributes may then be preliminarily identified and scrutinised for inclusion in the national MEPA network system.

Step 2: Concept Development for a Functional National System

The focus here is on detailed evaluation, stated above in table 1. Particular concern is with functional (ie. process-orientated) properties -- biological diversity, hierarchies of scale, ecological processes, land-sea interactions, and human impact.

Task 1: Development of the GIS. A preliminary GIS may have been developed as a set of maps under Step 1, but now needs to be placed on a functional basis. A team of natural and social scientists and managers will need to be convened and data assembled as outlined in Step 1. The long-term goal of the GIS is to assist in the identification of an ecologically defensible and sustainable regional, national, or world-wide system of MEPAs, which carry out stated goals and objectives, and which may be subject to research and monitoring.

Task 2: Characterisation of environments: This task begins to create a regional, national, or global ecological characterisation of coastal-marine environments. It requires development of a more detailed biogeographical description of coastal and marine ecosystems units, and the assembly of more detailed data-sets. *This characterisation is hypothesis-driven and model-based,* for example, to address such hypotheses as expressed in Solbrig (1991b). This level of sophistication is a requisite for monitoring.

Task 3: Identification of the Network. This task examines the biogeographical classification as if no MEPA had been established -- *tabula rasa.* "Ideal" sites are identified independently of existing MEPAs in accord with the characterisation of *Task 2*. That is, sites should be conceived as part of a network that incorporates the scale features of ecosystems. Choice of sites should be based, to the extent possible, on quantifiable information (eg. related to disturbance, restoration, natural histories of indicator species, etc.). Sites may be derived from ecological models (eg. central place theory; Dyer & Holland, 1991). This task thus develops the conceptual basis for achieving a MEPA network. It also provides the basis for fitting existing MEPAs into a network system and its stated goals.

Task 4: Enhancing Public Acceptance. The list of existing and potential MEPAs identified by *Tasks 1 - 4* of Step 1 may now be compared with the conceptual network of Step 2, *Tasks 1-3*. New candidate lists may then be developed and submitted to social and pragmatic selection criteria to resolve such issues as:

* Which identified sites are publicly acceptable;
* How may each site relate to a global, national, and/or state system;
* Which sites offer the greatest potential for management;
* Which sites can be developed to demonstrate resource sustainability;
* How may public education be promoted; and
* How many sites are practically manageable within agency and budgetary restraints?

It may be found that some existing sites do not "fit" well within the conceptual network. This does not mean they should be discarded, but that they may be down-ranked in terms of priority for funding, research, and ecosystem representation. This comparison should also illuminate significant gaps for future MEPA network development.

Step 3: Refinement, Iteration, and Networking

This step is an on-going, long-term iteration of the above procedures, with the important goal of achieving MEPA networking. Ecologically sustainable use requires the interlinking of communications, research, monitoring, and management procedures. It is apparent that life in the sea cannot be adequately understood at single sites, nor can it be protected within the boundaries of a marine park or reserve. Networking among sites is a way out of this dilemma.

Fortunately, the development of a network is inherent in the strategic assessment process itself. In the US, *Long-Term Ecological Research Sites* provide an example of networking from a scientific point of view. Efforts are currently underway to evolve international networks for research on ecosystems (Lasserre *et al.*, 1994; Nottrott *et al.*, 1994). UNESCO Biosphere Reserves have networking potential, but have not yet developed networking capabilities (Ray & Gregg, 1991; Risser & McCormick-Ray, 1991).

Networking provides for cooperation and information-sharing, such as is proposed for the "information highway". A GIS provides the relational data base and tool upon which comparisons can be made. Through networking, MEPAs can be organised into functional groups to facilitate communication. Networking can have profound effects on policy, including the highlighting of particular issues to local, national and international concerns.

Additional Considerations

A Stronger Role for Science

Two present practices for MEPA implementation are at opposite ends of the scale: 1) establishment of geographically limited areas as refugia for endangered systems or species or for replenishment, and 2) regional multiple-use management areas. Both have obvious advantages, but also may pose problems. On the one hand, small areas rarely can be managed to take account of large-scale, regional influences, whereas large planning areas are so comprehensive that most attention is paid to zoning for multiple use, with insufficient attention being given to research and monitoring. The sobering reality is that there appears to be no large- or small-scale example of a marine protected area of any kind wherein resource sustainability can be demonstrated or is predictable for a reasonable time frame.

An attempt has been made to resolve this issue, at least on paper, namely the "biosphere reserve". For this paradigm, management is geared to designated, fully protected "core" areas that focus on operational objectives (Ray & McCormick-Ray, 1989; Kenchington & Agardy, 1990; Batisse, 1990; Ray & Gregg, 1991 -- see also other papers in the same *BioScience* issue). No matter what the paradigm, however, it is apparent that unless research and monitoring are instituted from the very beginning, MEPAs will remain at risk of failure. Their management will be a "seat of the pants" exercise based on guessing and ignorance, resulting in wasted time, money, and confidence.

Alternate Approaches

The urgency of obtaining a more detailed biogeography, or environmental classification, for a representative system is virtually unanimously agreed upon. Nevertheless, other approaches have been suggested, including a "taxic" (ie. taxonomic) approach (Margules *et al.*, 1988; May, 1990; Vane-Wright *et al.*, 1991). This approach is based on detailed knowledge of species, species groups, and/or species' genetics for evaluation of priority areas.

Unfortunately, any approach that uses species or species groups as the major starting point for coastal-marine MEPA identification and selection will face the severe restraint of basic ignorance that exists about species and their natural histories. The work of Grassle (1991) lucidly illustrates how little is known about the species of marine environments. Further, reliable taxonomy at the species level is a subject of major concern for many taxa (Knowlton *et al.*, 1992). For fishes, we have relatively good knowledge about taxonomy and range, but this knowledge does not extend to distribution, variability, and natural history, even for relatively well known commercial species.

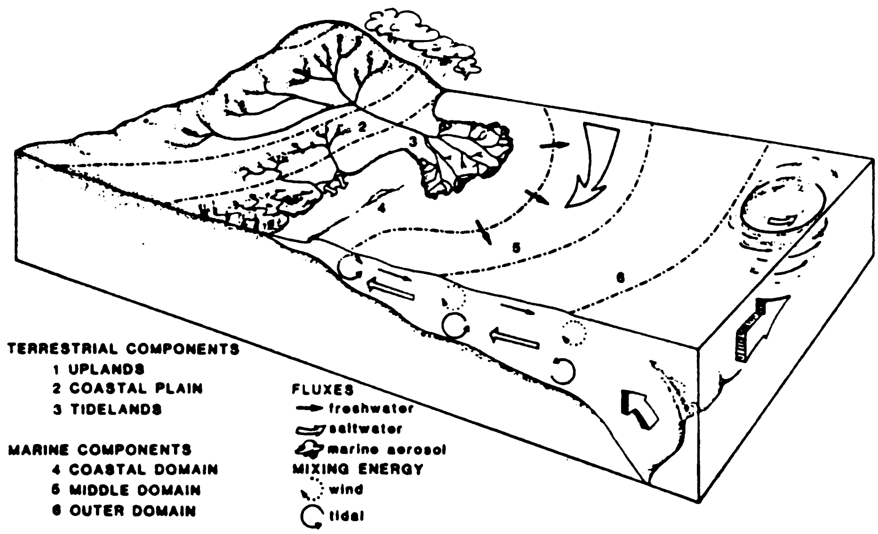
Science and knowledge of how the world works is evolving rapidly and the development of new knowledge tells us that there can be no "best" scale for representation, nor a "final" number of MEPAs. No matter what approach is used for MEPA establishment, the three essential requirements are: 1) that they have a firm basis in natural and social sciences; 2) that decisions are ultimately based on the integration of this knowledge; and 3) that they are locally supported and adequately funded.

Our Inherited Baggage

Our inherited baggage is mostly inherited from conservation practices that have historically been land-based and species orientated. The consequence is that society, as well as many conservation practices, are still driven by terrestrial thinking and narrow paradigms. This is exemplified by the creation of "wet national parks" and the overwhelming concern for endangered, large, charismatic species such as marine mammals, birds, and turtles. One assumption is that protection of large species with wide ranges -- the so-called "charismatic megadiversity" (Mittermeier, 1986) -- will also protect the little species. Unfortunately, this assumption has little scientific evidence to support it, especially for marine systems. We must continually be reminded that the overwhelming portion of marine biodiversity consists of small animals and plants. Relatively little interest -- even in conservation circles -- is shown toward protecting plankton, jellyfish, oyster reefs, or the productivity and integrity of marine systems.

There is also baggage based on simplistic, conventional wisdom. One example is that the sea is a three-dimensional continuum, or an open system, within which the distribution of species or the effects of pollution result from "downstream" effects; we also read that species' "habitats are rarely precisely or critically restricted" and that in sea "endemism is rare" (Kelleher & Kenchington, 1992). In fact, all species -- terrestrial and marine alike -- are restricted in range and distribution by physical and/or biological factors and all species are endemic at some scale, regional or local. Furthermore, biotic communities respond the complex boundaries that may occur within coastal-marine systems, as illustrated in figure 6 (Ray, 1991).

Figure 6.
Hydrographic Boundaries of the Coastal Zone (Ray and Gregg, 1991)



These boundary conditions are real and discoverable, but have been paid insufficient heed in MEPA planning, management, and establishment. In short, the coasts and seas are highly complex and far from simply continuous.

Thus, how ecological boundaries are determined is central to MEPA establishment. For scientific or management purposes, an ecosystem should be perceived and defined in an operational context -- that is, the goal or objective for management defines the scale and boundaries of the MEPA and the rationale for sustainable management. This is to say that the pattern seen as a characteristic of ecosystems is neither solely a property of the ecosystem nor of the observer, but of the interaction between them (Levin & Kimball, 1984).

Finally, we often hear the tautology that marine conservation is not ecosystem or species management, but management of human activities. This perspective seems to derive from difficulties and/or misunderstanding in applications of ecosystem science. It places management on a sociological platform. Paradoxically, there seem to be few doubts that humans have learned to manage many terrestrial systems to their own purposes -- farms and forests, for example -- at times with disastrous results, but occasionally sustainably. Humans already manage some coastal, near-shore systems for waterfowl and the like. The coming age of biotechnology predicts large-scale marine ecosystem management, with major impacts on marine biodiversity and ecosystem function. Predictive models have been in development for at least a decade that will prove to be enormously helpful for ecosystem management, and which include humans in the paradigm.

The Problem of Fisheries

Perhaps the most serious portion of our inherited baggage concerns fishing. Fisheries present probably the most pervasive and historically important human perturbation of the global coastal and ocean zones. Few MEPAs prohibit fishing, and within the great majority of MEPAs, fishing is very liberally regulated as a component of multiple-use management.

The emerging consensus is that continuation of massive removal of ocean predators not only results in the depletion of fishes, but also in alteration of the habitats on which they depend. Parsons (1991) states that "...indications of changes in the ocean ecology due to the removal of fish are given in widely scattered reports." Angel (1991) puts the matter boldly: "It seems scarcely credible that such extensive cases of exploitation have not had major impacts on the structure of the ecosystems concerned, and the energy flow within them."

It seems clear that there is much to be gained by more extensive fishery closures and by monitoring the effectiveness of closure on both fishery enhancement and overall ecological function. NOAA (1990) discusses clear advantages of fishery reserves for fishery management and proposes: "...a mixed management strategy...where 20% of the shelf is MFR [Marine Fishery Reserve] while the remaining 80% is managed for optimal yield by any of several traditional options."

MEPAs can be shown to have a positive effect on both fish and fisheries. Alcala and Russ (1990) have estimated that when 25% of a sub-tidal coral area in the Philippines was closed to fishing, the result was "significantly higher yields to fishermen adjacent to the reserve." Bell (1983) had previously shown that for an area of the Mediterranean "reduced fishing pressure in the reserve has provided effective protection for species vulnerable to fishing." Both studies imply benefits to fish communities, to their ecosystems, and to fishery production. This has been borne out by experience in New Zealand (Ballentine, 1991). Large areas closed to fishing also exist in Australia and the Bahamas, but data on possible benefits are not yet available.

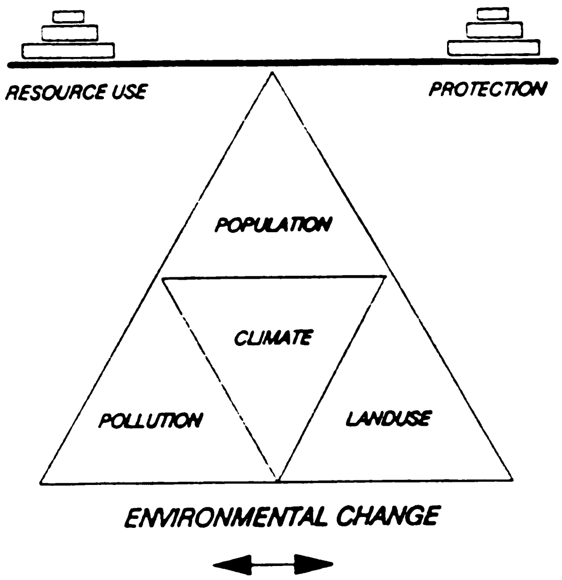
A Need for New Paradigms

Sharp breaks with the past are to be avoided, as there is little to be gained by "throwing out the baby with the bathwater." However, the emphasis in the past has been on *ad hoc* tactics. Now, it seems apparent that there is a continual need for re-examination of procedures and objectives, as well as increased emphasis on science-based strategic approaches. Most importantly, MEPAs must address the three goals stated under "vision" above, and do so *simultaneously*, while also attemping to achieve a "balancing act" between resource use and protection, in a context of environmental change (figure 7).

The new paradigms must provide clarity about objectives for MEPAs. "Resource protection" is subject to broad interpretation. According to IUCN guidelines, protection includes a range from strict to "multiple use." But one may ask: is the purpose of management to *protect* the resource, the habitat, or the ecosystem *for* human use *or* to maintain an ecosystem's natural productivity or diversity? How are "resources" to be defined? Is resource protection the fundamental goal for *every* MEPA or can compatible use, restoration, research, and education also be fundamental goals? Can use and protection co-exist?

Methods and data are now sufficient to develop a coastal-marine, hierarchical biogeography for purposes of guiding the development of a representative network of MEPAs, based on ecological patterns and processes, and human uses and impacts. Ideally, biogeography should

Figure 7.
The "Balancing Act" of Marine Protected Areas



be used to interpret mosaics of pattern that are related to causal processes and that are discernable and describable in quantifiable terms. The emergent science of landscape ecology and the development of computer-based GIS technology offer significant insights and tools for this purpose (Forman & Godron, 1986; Urban *et al.*, 1987). By these means, a global network should be *idealistically designed as a model* to be realised over the long term. This vision should be made clear. Unfortunately, there is an expedient tendency to speak to the lowest common denominator in proposing MEPAs and their management, resulting from consensus-based participatory processes. This is self-defeating in the end -- perhaps sooner than later.

Nevertheless, no matter how good the data are and no matter how complete the analytical methods for MEPA establishment, we must face the major continuing problem that institutions and management procedures continue to lag behind existing knowledge. The policies, mandates, and missions of agencies and the rigidity of institutional structures offer considerable impediments to cooperative exchanges and to the coordination of regulatory laws. SCERA (1991) notes that the consequences of the "tyranny of small decisions" and the "fragmented structure of decision making" has led to "public disillusionment." Odum (1989) has pointed to the "social traps" and "worrisome gaps" that impede conservation -- many of which occur within conservation itself -- which must be addressed and corrected. All this means that ultimately the utility of MEPAs to science and society will have to become the recognised forces with which to alter political will.

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Understanding larval dispersal and habitat connnectivity in tropical marine systems: a tool for management

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Abstract

Computer models have been developed which are able to reproduce large scale patterns of water motion around Australia's Great Barrier Reef and the movement of larvae between reefs. These models, based on well understood physical principles, determine the probability that larvae from any given source reef will be carried to a sink reef where they will develop into adults. This paper summarises efforts aimed at such modelling of 46 important reefs of the Great Barrier Reef and discusses implications for the management of the Great Barrier Reef Marine Park. With increasing human pressures upon reefs in the Great Barrier Reef Marine Park, stress on reef communities can be minimised through zoning schemes that incorporate information about source-sink relationships. In many marine systems this is especially important since the ability of a system to recover from stress will depend largely on the availability of juveniles to the population.

Introduction

Most tropical marine invertebrates and fish reproduce by means of pelagic larval development. The duration of larval life varies between several days and many weeks, during which larvae have the potential to disperse widely. There is growing evidence that tropical marine systems, particularly coral reefs, should be viewed as a series of strongly interconnected habitats. Furthermore, recent advances in our understanding of the population structure of coral reef fish and invertebrates suggest a relationship between population abundance and the physical oceanographic processes that transport larvae.

The reproductive strategy of most invertebrates and fish has, therefore, significant implications for the management and conservation of tropical marine resources. This has been recognised and incorporated in the planning and management of the world's largest multiple use marine protected area: the Great Barrier Reef Marine Park in Australia. As a management tool, understanding habitat connectivity by means of studying larval dispersal can provide the basis for ecologically sustainable development. Numerical models capable of simulating the hydrodynamics and dispersal of larvae between habitats within the Great Barrier Reef have been used to describe relationships between individual reefs. The protection of priority areas within the Great Barrier Reef Marine Park, such as those reefs with high potential as sources of larval recruits, can ensure a continual supply of resources to exploited areas.

The Great Barrier Reef is a complex maze of coral reefs that stretch more than 2,000 kilometers along the northeastern coast of Australia (Figure 1). Approximately 2,900 individual reefs and islands provide habitat for an enormous variety of organisms, together constituting a marine system of global significance.

Such an ecosystem inevitably attracts considerable pressure from recreational and commercial users. In this case, the diversity of uses, ranging from reef walking to shipping, naturally leads to conflicts among some of the user groups. Furthermore, users are themselves pitted against those who would like to see the reef system preserved in a pristine state (Kelleher, 1986). In recognition of existing and potential conflicts, and the great value placed on the Great Barrier Reef by most Australians, the Australian government in 1975 passed legislation establishing the Great Barrier Reef Marine Park Authority (herein the Authority). The Authority is charged with the responsibility of recommending areas to be included in the Great Barrier Reef Marine Park (GBRMP) and with preparation and implementation of management plans based on multiple use zoning (Kelleher, 1986).

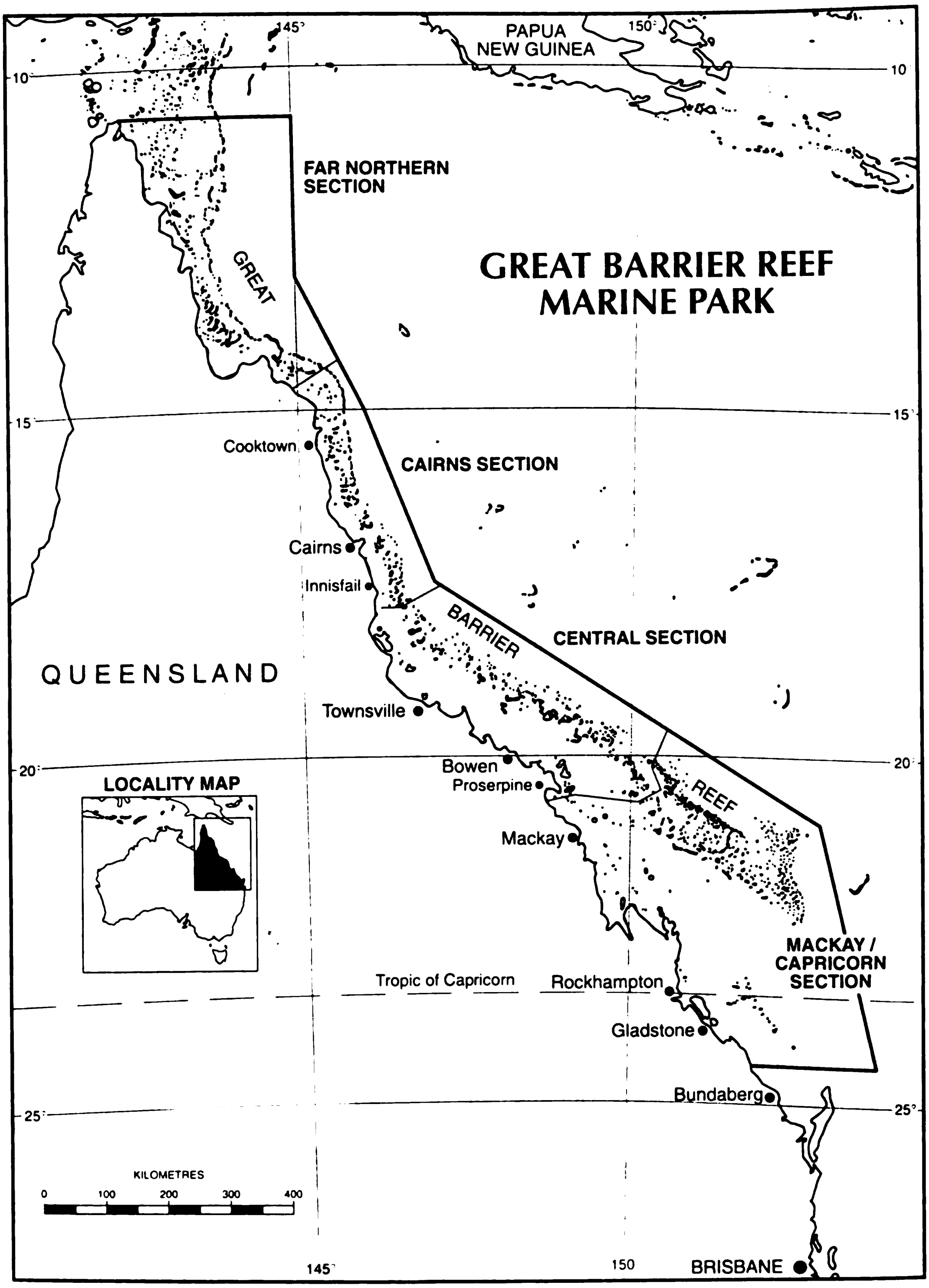
Zoning can be an effective management tool enabling the physical separation of conflicting uses and the establishment of varying levels of protection of resources. The GBRMP is divided into sections with individual zoning patterns. The entire marine park area has now been zoned, with three main categories of protective status: 1) General Use, in which almost all human activities are permitted; 2) National Park, from which commercial activities are excluded; and 3) Preservation and Scientific Research, from which all recreational and commercial activities are excluded (Kelleher & Stark, 1988).

Recognising that knowledge about the reef ecosystem is incomplete, flexibility is provided through the power to temporarily designate areas requiring special protection from time to time, such as nesting or breeding sites. The zoning plan for each section is maintained for approximately five years, after which the plan is reviewed and, if necessary, revised.

The Authority seeks, wherever possible, to base zoning decisions on objective scientific arguments. An important component of the scientific knowledge base for reef systems is their underlying physical oceanography. There is growing recognition of the need to understand water movements and the resulting transport of both larvae and nutrients, since these determine the extent to which zones can be considered in isolation rather than as interconnected components in a complex ecological system.

Many coral reef organisms produce pelagic larvae that are carried a considerable distance from their source reef before settling and developing on a sink reef. Generally speaking, it may be possible to minimise stress on reef communities by taking account of source-sink relationships

Figure 1


GREAT BARRIER REEF
MARINE PARK
PAPUA
NEW GUINEA
FAR NORTHERN
SECTION
CAIRNS SECTION
CENTRAL SECTION
MACKAY /
CAPRICORN
SECTION
GREAT
BARRIER
REEF
QUEENSLAND
LOCALITY MAP
Cooktown
Cairns
Innisfail
Townsville
Bowen
Proserpine
Mackay
Rockhampton
Gladstone
Bundaberg
BRISBANE
Tropic of Capricorn
KILOMETRES
0
100
200
300
400
145°
150°
10
15
20
25
150

among reefs, when determining the zoning plan. The ability of a reef community to recover will in part depend on the availability and fate of juvenile recruits. Thus reefs that behave as good sinks for fish and coral larvae may be better able to support sustained exploitation.

It can also be argued that highly effective source reefs play a significant role in the population dynamics of many reef organisms and should therefore be protected. A source reef is deemed to be effective if larvae originating from it readily encounter suitable habitat on other reefs as they are advected by water movements forced by the wind, tide, and the East Australia Current. Reefs with larvae that tend to be broadly (if weakly) dispersed to many other reefs may be selected as high priority reefs which serve to ensure a regular supply of larvae to the system. On the other hand, to ensure regular recruitment to a particular reef or group of reefs that is under exploitation, a source reef should be selected for protection on the basis of the strength of "connectivity" from it to targeted reefs.
It has recently been suggested (James *et al.*, 1988) that reefs in the northern half of the Cairns Section form a partially-closed self-recruiting system that behaves as a centre from which populations to the south are maintained by larval dispersal. It would therefore be important to ensure that a connected set of reefs with protective zoning, stretching from north to south, exists to facilitate the supply of larvae throughout the Cairns Section.

To test the potential effectiveness of GBRMP zoning, *viz a viz* the ability to protect the most important source and sink reefs, a transport model was developed and applied to numerous reefs in the Cairns Section. The modelling work described in this study was commissioned by the Authority to study the effectiveness of certain reefs in the Cairns Section of the GBRMP as sources of larvae for recruitment of organisms to other reefs in the area. The objective was to evaluate the role played by reefs which, in the existing zoning plan, have a protected status of Marine National Park "B" and above. A second phase was then undertaken to evaluate an additional 21 reefs in an attempt to identify reefs requiring upgrades in protected area status.

Modelling

The methods used in this prócedure have been described in detail in James *et al.* (1988). The simulation of larval dispersal is based upon the numerical hydrodynamic model SURGE (Sobey *et al.*, 1977).

SURGE generates output representing astronomical tides, wind-driven flows, and the East Australia Current (EAC). These provide the database characterising the current pattern for all combinations of wind, tide and EAC by which advection and dispersion of larvae are simulated. The hydrodynamics are two-dimensional and depth-integrated, and are resolved at a grid scale offive nautical miles. SURGE is well-tested and has been validated within the GBRMP.

The principal assumptions underlying the dispersal model are: 1) that larvae behave as passive particles, 2) that they are well-mixed throughout the water column, and 3) that they will be advected off their natal reef and transported by mainstream circulation. Simulation of the advection and dispersion of larvae runs under time-dependent tidal flow and a varying wind field are derived from the historical record at Low Isles. The state of the tide over a 28 day cycle and the wind record on which to begin particle tracking are randomly selected to represent the initiation of each dispersal event. The ensuing sequence of wind speeds and directions determines the variations in wind-driven current patterns for the duration of larval transport. Since the behavior of crown-of-thorns larvae provided the motivation for the development of these computer programs, the wind record segments correspond to spawning and dispersal season of the starfish. The dispersal patterns of organisms that spawn on other times, or at well-defined points in time, cannot be expected to be well reproduced by the models.

For each of the 25 reefs initially investigated, forty dispersal events were simulated: twenty from each of two different locations on each reef. Each event was simulated under a different randomly selected sequence from the wind record. The analyses were carried out for two distinct cases: 1) organisms with a long precompetent period, requiring 14 days development in the water column before settlement onto a suitable substrate, and 2) organisms with a relatively short precompetent period of only four days.
The contributions from forty runs were summed from each source reef and the final connectivity value was computed by dividing the result by 280 (the total number of particle trajectories analysed for each reef). This gave a relative measure of the strength of connectivity between each source reef and each sink, expressed as a proportion of the total number of particles exported from each source area.

When all the simulated trajectories are plotted together, gaps in coverage are readily identified for these particular source reefs. Coverage appears to be rather thin and patchy, especially in the southern half. There is a large region of poorly-served reefs extending from just north of Cairns to just south of Cooktown, and smaller areas south of Cairns and near Innisfail.

Application to the GBRMP Zoning Plan

When the Cairns Section Zoning Plan was initially prepared in 1982-1983, there existed only limited understanding of the system dynamics of the Great Barrier Reef, and little data on reef use. However, several reefs off Cooktown were zoned Marine National Park "B" because of empirical evidence on the pattern of crown-of-thorns spread between 1965 and 1975. The latter evidence suggested that those reefs may have been a source of crown-of-thorns recruits that caused the large population outbreaks first observed off Cairns between 1962-65 (Kenchington, 1977). That first zoning plan was produced based on the best available scientific information.

A review of the Cairns Section Zoning Plan commenced in 1988, primarily because there were significant changes in the patterns of use since the plan was first prepared. Since recruitment affects recovery from use-induced stress, the larval dispersal model was incorporated as a planning tool in the zoning review. This allowed the relative importance of particular reefs to be assessed, and the incorporation of ecological processes as part of decision-making in the preparation of management planning.

The 25 reefs initially selected for analysis by the model are those that were zoned with a high level of protection in the original Cairns Section Zoning Plan. The results of modelling indicate that the levels of protection afforded were not effective. A further 21 reefs were modelled as larval sources, and those that were deemed of high potential were proposed for new protective zoning. Several reefs had their protected status upgraded in the proposed new plan. For eight of these, the results of these studies played a part in the decision to upgrade. In one case, a downgrade was proposed based on the results of this modelling. Other factors that were considered in the zoning review were the ecological importance of the area, its existing and desired future use, proximity to population centres, and the representativeness of the reef type in the Section and in the GBRMP as a whole.

Conclusions

The identification and protection of a series of key source and sink reefs is considered to be a high priority for the Great Barrier Reef Marine Park Authority. As with all management, the planner is obliged to make decisions by applying the best information available at the time. Planners involved in the GBRMP Zoning Review believe that any modelling capabilities that assist in understanding ecological processes of the Great Barrier Reef, and which enable more rational decisions to be made about zoning, should be considered. As improvements in modelling methods are made, such tools become even more valuable to marine park managers.

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Application of core and buffer zone approach to marine protected areas

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The Biosphere Reserve Concept has been defined to include the three goals, concerns, or roles, of conservation, research and sustainable development (Batisse, 1990; Kelleher & Kenchington, 1992). These same goals relate directly or indirectly to a wide variety of other protected areas and alternative management regimes. If there is any hope of achieving any of these three goals, it is absolutely imperative to find ways of establishing adequately-sized and sufficiently-protected core areas and surrounding buffer zones. As suggested in a *Bioscience* article entitled "Are Conservationists Fish Bigots?" (McClanahan, 1990), compromises have been made too often with regard to both the size and levels of protection afforded by marine protected areas (MPAs) especially with respect to harvest, followed by bewilderment when they do not achieve their goals. Without adequately protected and sufficient core areas, marine biosphere reserves and other MPAs are doomed to failure not only with respect to their conservation goal, but also with regard to both research and development concerns.

Applicability of core and buffer concept to marine areas

The nature of many marine organisms and certain threats facing them are particularly well-suited to the area and buffer concept. The vast majority of marine organisms have life histories involving relatively sedentary adult forms with pelagic dispersal occurring during a larval phase. Such a life style may be especially well-suited to core and buffer management, depending on the nature of threats, provided that strong protection of core areas ensures adequate recruitment to non-core areas. For such organisms, the core and buffer concept can be ideal for dealing with the variety of marine threats. Core area protection may be the best way to manage some of these threats such as over-exploitation and certain direct physical impacts. Conversely, threats such as pollution and other indirect impacts to habitat that do not respect arbitrary lines drawn in the aqueous environment may necessitate a buffer zone approach. Long-lived, slow-growing organisms with life history traits including a relatively sedentary adult stage, delayed reproduction, high fecundity that increases with age, geographically restricted adult distribution linked to specific habitat, and extended larval dispersal -- especially those facing severe over-exploitation or direct physical impacts -- may be ideal candidates for core and buffer management.

The need for core zones beyond small critical areas

The argument for identifying and strongly-protecting small critical ares including key spawning, nursery, juvenile-rearing, feeding, migratory stopover or bottleneck sites; migratory corridors; and areas of high diversity and productivity; has already been made and is compelling. Not all areas are equivalent and priority must be given to providing such locations core area protection. Furthermore, the idea of being able to focus core level protection on a few small areas is very appealing. However, this approach for delineating core areas has a number of limitations, can not be relied upon exclusively, and is insufficient to provide adequate protection unless broadened to such a degree that it loses its meaning.

The first limitation to such an approach is that critical area requirements may vary from species to species. This limitation is exacerbated by the fact that for most species we do not know what is critical and will not for the foreseeable future. Second, even with species for which key spawning sites and other critical areas can be identified and protected, such protection will not be adequate if insufficient spawning stock escapes exploitation or other threats when outside these areas. Finally, even when this approach succeeds in conserving biological diversity at the species level, it may still fail to conserve diversity at the ecosystem or genetic levels. This is especially true for systems subject to heavy exploitation.

An alternative approach: Set aside significant portion of area as harvest refugia/replenishment/non-consumptive/ natural/wilderness/ scientific research reserve/stable reference/true/zone or area

An alternative, additional, and complementary approach to core area selection involves setting aside significant portions of the marine area or region that may or may not correspond to critical or special areas for core level protection. The distinction is that the whole portions/areas/ systems/chunks are set aside and afforded true protection as complete units rather than small, individual, components protecting certain critical values. Although these approaches are not mutually exclusive and can be combined to grade into one another, I believe there is a subtle, yet fundamental, difference between them that I hope I have been able to convey. Perhaps the key difference is what the second approach abandons the attractive idea that we can get away with setting aside only a tiny fraction of the entire area, the most critical, for strong protection and leave the remainder as buffer.

The importance/necessity of establishing strongly-protected core areas including harvest refugia within a marine biosphere reserve or other MPA applies to its conservation, research and sustainable development goals. Specific benefits can include:

1. Conservation of critical spawning stock biomass, population stability of exploited populations, intraspecific genetic diversity, natural population age structure, and

examples of areas in natural equilibrium and ecosystem balance.

2. Provision of research opportunities relating to unexploited or natural populations, areas in natural equilibrium and ecosystem balance, special fishery research areas, minimally disturbed sites, and differences between exploited or otherwise impacted areas and areas not so affected.

3. Provision of stable reference or control sites which if properly designed can be used to evaluate impacts or effects of various management regimes, activities, or threats.

4. Insurance of sustainable harvest by preventing recruitment failure and stock collapse via protection of spawning stock biomass, and maintenance of population age structure and intraspecific genetic diversity.

5. Enhancement of non-consumptive economic activities.

6. Persistence of sustainable trophy fisheries via migration from core areas and resulting re-stocking.

Design and scientific support

The recent refocusing of attention in marine ecology on recruitment processes known as "supply-side" ecology has offered some support and recommendations for designing marine reserves. Fairweather (1991) has summarised some of these ideas including 1) the importance of near-shore habitats such as seagrass beds and mangroves as recruitment and nursery areas and the consequent suggestion to include such areas in reserves; 2) the need to protect a variety of habitat patch sizes and locations for different organisms; 3) the relevance of scale of dispersal and larval connectivity to defining management units; 4) the idea that marine reserves may contribute recruits to distant areas; and 5) the desirability of including source areas within marine reserves. Such recommendations are consistent with the *Guidelines for Establishing Marine Protected Areas* (Kelleher & Kenchington, 1992) suggestion that significant breeding and nursery areas be strongly protected and that strongly protected zones should include as many different habitat types within one unit as possible. Finally, Fogarty *et al.* (1991) modelled the impact declining spawning stock biomass has on reducing recruitment possibilities and favouring stock collapse. This conclusion re-emphasises the importance of protecting that biomass.

Scientific uncertainty and risk

While some uncertainties may exist with regard to size, number, and location of such core area refuges; enough is known for at least some systems to experiment with setting up models, monitoring, and adapting them over time in response to what is learned. Although the idea of experimenting with design may seem risky, there is little risk involved especially for heavily exploited sites. The absence of risk is due to the alternative which is nearly certain failure.

Experience/Examples/Documentation

Despite the limited number of marine areas set aside as protective reserves, evidence is beginning to accumulate that documents their effectiveness and value. Perhaps the best example is the Leigh Reserve in New Zealand which has been completely closed to all types of fishing since 1977. Since 1977, considerable change has occurred within the reserve as it returns to a more natural state. Research on this site has yielded a number of interesting and surprising findings with the important management implications that were directly dependent on the reserves unexploited status. Spawning stock biomass of many species within the reserve has increased greatly (Ballantine, 1991).

Work on reserves in the Philippines, Cayman Islands, Chile, and Belize have yielded similar findings. Even at Key Largo and tiny Looe Key sanctuaries in Florida, where only spearfishing is totally banned and considerable fishing continues, significant changes have been documented in reef fish abundances since the spearfishing was outlawed (Clarke *et al.*, 1989).

New directions

A number of recent initiatives hold promise for developing the true reserve concept more fully. These include work involving coral reef fisheries in Australia, Bermuda, and Florida; invertebrates in the North Pacific; and temperate reef species in California, New Zealand and Australia (AFS, 1991). One of the most promising of these new initiatives involves a proposal to establish extensive marine fishery reserves covering 10-30% of the continental shelf off the southeastern US to halt a precipitous decline in snapper, grouper and their reef fish stocks due to overfishing (Bohnsack *et al.*, 1990). Another promising initiative is the zoned management plan currently under development for the Florida Keys NMS. There is hope that this plan will include a variety of zones that can aid research aimed at determining which of a number of potentially harmful activities are responsible for a significant decline in Florida's reef tract system.

Conclusion

Not only are strong protective core areas desirable for conservation, but they are necessary for both sustainable development and appropriate research. The question that should be asked is not whether they should be established, but how and how large a portion should be so dedicated.

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Whales, science and protected area management in British Columbia, Canada

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Abstract

The coastal waters of British Columbia are home to seasonal concentrations of two species of whales, grey (*Eschrichtius robustus*) and killer whales (*Orcinus orca*). The aggregations have engendered considerable attention from researchers, commercial whale-watching operators and recreational boaters. At one site whale concentrations have caused authorities to designate a small protected area, at a second site protection is informal. Current management plans include a mixture of are designation, guidelines and "soft" enforcement.

There is ittle scientific foundation for establishing the marine protected area, or in the implementation of management programmes. In 1985 a research programme was initiated to assess the potential impact of recreational use of whales and the nature of demand. It is the purpose of this paper to examine some of the needs for both social and natural science information in the development of marine protected areas and their management that have arisen as a result of the research.

Introduction

When the mandate of a protected area includes the conservation of free-roaming animals there is a need for the inclusion of specific autecological and synecological information in both the initial design and management of the area. Similarly, when the scenario includes human interaction, as virtually every protected area does, there is a requirement for social science information. The human element can no longer be managed under the simple models that have characterised the human dimensions of protected area management in the past.

Perhaps nowhere are the problems of matching wild animal ecology, human dimensions, and the administrative simplicity of area protection more clearly illustrated that in the case of marine parks and reserves. This paper will focus on the specific case of establishing reserves to protect whales. Management of wild whales has historically depended on a theoretical exercise in population modeling that carried little relevance to reality (Holt, 1985). As a result managers incorrectly estimated sustainable harvest and failed to protect large whale stocks from risk of extinction. As our interactions with whales changed over the past 25 years, we have expanded the management paradigm to include protection of both whales and habitats (eg. National Parks Service 1984, Canadian Parks Service, 1988), recovery of the endangered populations (National Marine Fisheries Service, 1989), and the management of recreational nonconsumptive use (Duffus & Dearden, 1991).

At this juncture the difficulty with reserving areas in the marine environment comes to its problematic apogee, setting aside an ecologically significant volume of ocean for a species group whose spatial domain is unknown, and, within that imposing management plans that mediate human interaction at levels suitable to the maintenance of healthy population functions. This somewhat daunting task has been attempted in several cases. In the Gulf of St. Lawrence on Canada's east coast, areas have been set aside for endangered beluga whales (*Delphinapterus leucas*) and human behaviors mediated to try and protect a failing relict population (Department of Fisheries and Oceans, 1989). Similarly in Hawaiian waters, federal authorities attempted to establish a National Marine Sanctuary for humpback whale (*Megaptera noveangliae*) calving/nursery areas, although local authorities blocked the Sanctuary's establishment as a barrier to development. The International Whaling Commission allowed a non-whaling zone to be established in the Indian Ocean. Mexico established a National Park over the gray whale (*Eschrichtius robustus*) calving lagoons at Laguna Oje de Libre.

This paper will focus on the role of science in the establishment of management measures for two concentrations of whales on the Pacific coast of Canada where recreational use and resource management conflict have reached the point where the public has called for intervention. By focusing on these specific cases, the paper will endeavor to illuminate some of the important contributions science can make to the design and management of marine protected areas.

Case studies

Whales concentrate at two locations on the Vancouver Island coast. Grey whales that do not undertake the entire migration with the bulk of the eastern Pacific population north from the wintering area along Baja, California, Mexico and the summer feeding grounds in the Bering Sea spend the summer feeding the bays and inlets on the western coast of Vancouver Island (Figure 1). The research described here focuses on individual and small groups feeding and travelling in southern reaches of Clayouquot Sound. Killer whales also form a summer feeding aggregation on the northeast coast of Vancouver Island in Johnstone Strait. Small matrifocal subpods utilise a core area for various periods throughout June, July, August and September to take advantage of migratory pacific salmon (*Onchorhynchus* spp.) stocks as they pass though the narrow Johnstone Strait.

Recreational whale-watching has developed over the past decade at both locations, and other water and land uses also have the potential to impact the local ecosystem. No protective designation has been made over marine areas for the conservation of the grey whales, while a provincial Ecological Reserve currently covers a small part of the marine area used by killer whales. In theformer case, we will discuss the use of scientific information applicable to the design of a reserve, and in the latter, comment on the use of science in the post-designation management of the reserve.

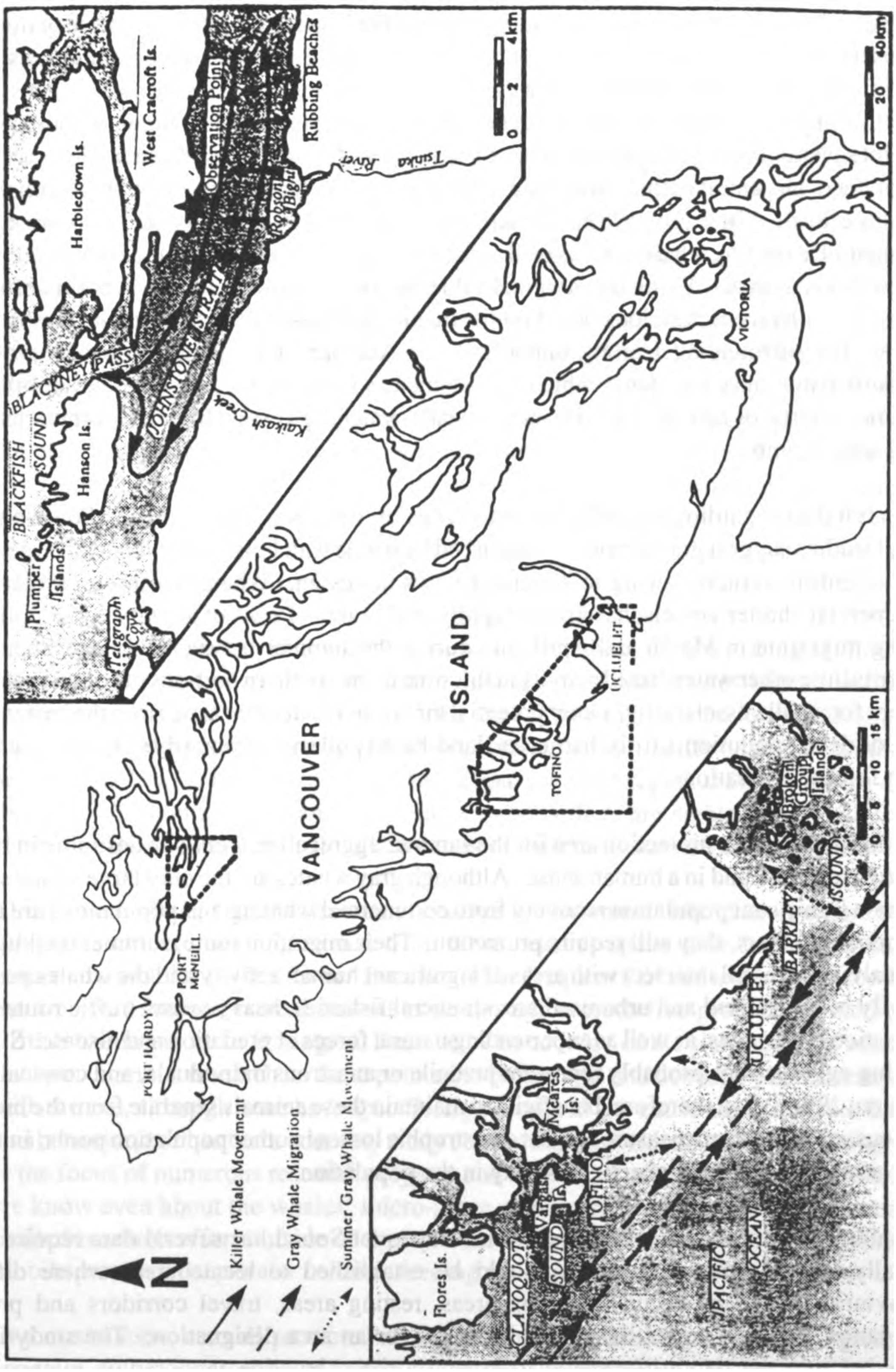

Figure 1
Sites of Whale Concentrations in Vancouver Island

Grey Whales of Clayoquot Sound

As grey whales leave the main migratory group on the Vancouver Island coast, they distribute themselves to take advantage of economical feeding opportunities from a number of sources. Feeding behavior of the species is known from several locales, although the mechanisms of food selection and the predator-prey dynamics are poorly understood. In Clayouquot Sound, whales exhibit several feeding strategies that have implications for their spatial distribution. They may either feed on suprabenthic swarming invertebrates, or feed on benthic organisms in the substrate itself (Guerrero, 1989). When food sources have been located and are deemed substantial, a feeding whale itself as well as the food source attract others, creating aggregations of four to six animals. Using the marginal value theorem (Charnov, 1976), an optimal foraging strategy results from desicions based on the quality and quantity of food in one site balanced against the surrounding feeding opportunities. Another factor in this equation would be predator disturbance avoidance which may instigate a switch in feeding site. Perhaps the most common source of potential disturbance is whale-watching vessels from the commercial fleet of nearby Tofino.

Research data regarding the influence on whales by vessels is inconclusive. Some observational studies suggest gray whales are disturbed by whale watching activity, but these generally lack scientific veracity owing to structural flaws in design. Whale-watching, primarily via commercial charter vessels, has grown rapidly in this area. Peaks of activity occur during the spring migration in March and April, and during the summer between July and September. There is little other water-based activity at this time in the southern portions of Clayoquot Sound except for small vessel traffic. Other potential threats to whales that arise from the larger region include debris pollution, oil discharge, and land-based pollution, primarily suspended sediment from forestry operations.

The designation of a protection area for the summer aggregation would be desirable in both an ecological sense, and in a human sense. Although gray whales are the only large whale species to show significant population recovery from commercial whaling and populations are near to historical numbers, they still require protection. Their migration route, summer feeding areas and calving areas all intersect with areas of significant human activity and the whales pass near heavily industrialised and urbanised areas, several fisheries, heavy vessel traffic routes, high recreational use areas, as well as experiencing natural forces of predation and disease. Summer feeding aggregations probably represent juvenile or anestrous individuals, and cow-calf pairs (Swartz, 1986). It is, therefore, beneficial to maintain these animals separate from the breeding nucleus asa short-term measure against catastrophic losses in other population pools, and in the long term as a source of genetic diversity in the population.

Planning and design of a whale reserve in Clayoquot Sound has several data requirements. Initially, spatio-temporal patterns should be established to locate areas where different behavioral sequences occur. Feeding areas, resting areas, travel corridors and predator avoidance sites will create the spatial blueprint for an area designation. The study is then extended into the depth dimension to ascertain the submarine topography, materials and ecosystem characteristics. Within each three dimensional space, planners can then implement mediative measures for human activities. The initial step is to describe the range and timing of activities within the boundary, then develop plans for buffering the reserve from outside impacts. Thus behavioral, ecological, and bio-physical plans are required to incorporate grey whale time budgets, substrate types, feeding ecology, differential use of space, human activities, and their impacts.

Our current research program developed a preliminary data base of time budget and use of space. Whales were visually located on 33 days between 4 July and 26 August, 1991. Location and behavior were recorded at all times, and data was subsequently mapped to provide a basis on which to carry on further study. In 1992, we will record and map locations of all whales encountered. Ocean bottom maps, including substrate materials, and prey distribution will be created using combinations of bottom samples and side scan sonar as well as direct observation and mapping. The whales and biophysical data will be analyzed on a GIS system to develop an understanding of the feeding ecology-spatial system. This will not only provide us with the dimension of one important site, but will provide a knowledge of the variables that constitute habitat for the summer feeding aggregations. If these can be further mapped on a regional basis, coupled with historical information on whale movement pattern then some estimate may be forthcoming of other areas suitable for protection to conserve and manage the whales and their recreational use.

Killer Whales of Johnstone Strait

At the second site, killer whales have been studied for about 15 years (Bigg *et al.*, 1989). The aggregation is part of a range contraction in a group of 180 whales known as the northern resident community, who congregate during the salmon migration in Johnstone Strait. At this time, the 17 subpods of the resident ecotype, which feeds primarily on fish, enter the Strait on an irregular basis travelling in cycles throughout the local region that range from daily to bi-monthly. Certain subpods are rare visitors, while others are sighted daily. Outside of the Johnstone Strait core area, little is known about their movements and behaviours.

The resident whales frequent two small beaches on Vancouver Island shore where they rub on substrate, and in travelling to and from these beaches spend time in a small bay and the outerestuary of the Tsitika River. Because of the frequency of use and affinity for these sites, the area was deemed critical and set aside through a protective program of the Province of British Columbia as an Ecological Reserve. The ecology of the site-organism relationship is unclear. Various researchers have pointed to behavioral and acoustic phenomena associated with the site, although none have specifically postulated any cause and effect link between site and behavior, nor has there been any study concerning its "criticalness". Interestingly, this site is the focus of numerous research projects, and is the core of whale-watching. The little that we know even about the whales' micro-range characteristics is at least in part an artefact of limited research effort outside of the core area. Furthermore, since feeding is primarily on mobile prey in a deep water column, feeding ecology has remained poorly known.

In that situation, a small protected area has been designated under the Ecological Reserves program of the Government of British Columbia. This measure has fairly limited potential to protect a marine area. It is a provincial designation, yet the federal government has jurisdiction over marine shipping, fisheries, and marine mammals. The only matter on which the provincial government has authority is recreational use, and land use on the adjacent shorelines and in the nearby Tsitika River Valley. Unfortunately, the Ecological Reserve's land area is small and narrow providing few buffering services to the marine area. All shipping, fishing, and the management of the killer whales are beyond the protective capabilities of the designation. Therefore, the boundary is highly permeable, and buffers to outside impacts are almost non-existent.

Managers need to utilise detailed knowledge regarding the nature of interaction between whales and fisheries, general and whale-watching vessel traffic, and the ecological links between killer whale presence and biophysical characteristics including water quality and shoreline characteristics. Some work has attempted to analyse whale response to whale-watching vessels but research has tended to focus on only few variables. Kruse (1991) concluded that whales travel faster in the presence of whale-watching vessels, although the conclusion is not based on the data presented. Further, there is no reasoning presented as to the effect of presence/absence in the current focus of governmental research (Briggs, 1991). The potential for intervening cause and effect linkages is high. Our past research, relying on simple behavioral categories has been similarly unable to discriminate between behavior sequences with and without watching vessels. Our current research examines observable behaviors and links these to potentially disturbing influence. None of the research has yet gone beyond the focus of recreational vessels, leaving the entire issue of influence by fishing vessels, which are ubiquitous during the summer in the core area, unstudied.

Studies in this area were largely unsuccessful in linking fisheries data to whale presence (Nichol, 1990), and no studies have been done to ascertain links between morphology, freshwater inflow, or water quality of the nearby Tsitika River. Currently, forestry operations are carried out in adjacent uplands that could potentially influence the shore environments.

The scientific knowledge on which this designation is based, and upon which the management is predicated, is almost non-existent. The whales do use the site, and the two beaches to varying amounts every summer. Beyond that there has been no research into the entire seasonal spatial domain, nor the relationships between this so-called "critical space" and other space in the whales daily range. Rather, the philosophy behind establishing such a small protected area within a larger range is what we term a "requiem" reserve: a place of rest. Unfortunately, since we know little of the nature of disturbance, especially concerning underwater acoustics which is the main subsurface sensory mode of killer whales, we are not able to assess a site in terms of its capacity to provide rest.

The total lack of scientific foundation may or may not obviate the utility of this reserve. It is known that for whatever reason, the whales do congregate there during an important feeding cycle and that may make it a high priority for protection. On the other hand, the fallacy of tokenism -- that is, giving the public the appearance of protecting an important whale habitat, when neither the importance of the site to the whales, nor the veracity of the protection is established -- creates a political "success" that may mask an ecological failure. Clearly, entitling this area a killer whale reserve is only justified in a semantic sense.

Human dimensions of whale reserves

Human dimensions of marine area protection may have little relevance for some sites while in others information requirements may be sophisticated. In both cases described above, there is a need for social science information as recreational use and resource use conflict are priority management issues. Research areas range from policy and institutional analysis, regional economic and total economic value studies and social impact assessment, to recreation satisfaction and motivation.

Management programmes arise out of policy milieux that frequently cross jurisdictional boundaries. With the advent of Exclusive Economic Zones, nations have taken on varying degrees of management authority in open waters, and with some species that migrate though the EEZ. Federal states, like Canada, frequently have arrangements with coastal provinces to allocate jurisdiction over resources among the most competent and appropriate administrative body. There are frequently cross jurisdictional aspects to many programmes, and a working knowledge of these sometimes informal processes is fundamental to understanding how protected area management fits into the wider scope of resource management.

A frequent management concern that develops at the initial planning stages of a protected area involves the potential costs and benefits to the local area. Marine protected areas may overlapfishing areas, transportation routes or effluent deposition sites. Thus protection may incur costs. Equally, protection may provide revenues to the local area as visitor service requirements expand. Both regional economic impact, as well as more complete valuation techniques will be useful planning tools to fit the protected area into the existing local system, and to inform players in various economic sectors of potential influences for mitigation, or development purposes. Both the examples discussed in this paper have significant economic implications as a result of recreational use demand. In both cases, significant infrastructure and monies flow into the service sector of what were formerly primary sector-based economies. Certain marine activities, like whale-watching generate fairly high indirect benefits to local economies as the activity is generally non-substitutable, creating steep demand curves.

Foregone opportunities may be part of management plans. In the case of the Johnstone Strait killer whales, economic activity in the adjacent forests and changes in fishing behavior may incur costs to the existing area users. A cost-benefit comparison would reveal not only the magnitude of the economic trade-offs, but also locate the different sectors to which costs are incurred and benefits accrue. In both that case and the gray whale case designation alters, or would alter, commercial whale-watching behavior, although in the long run it may support the longevity of whale-watching and provide opportunities to enhance the product.

The social domain of marine protected areas include aspects in common with terrestrial sites. Relationships between visitors and host communities, and stress on host facilities, as well as the recreational behavior may be more specialised due to the marine component, and types of use involved. Duffus and Dearden (1990) provide a framework for analyzing non-consumptive use in terms of both the site and the use by analyzing variables associated with growth of use, and the specialisation of the users.

Management of user behavior is simpler if the motivation, satisfaction, and the nature of demand is known. Planners can use fairly standard tools such as zoning, interpretation, and licensing for commercial recreation purveyors to adjust the fit of the protected area to the local environment.

Conclusion

Marine protected areas require more specialised planning than do terrestrial areas. Most of their complement of plants and animals go about their lives hidden from human view. Similarly many environmental changes, such as water quality, may go undetected. Within the human domain, most visitor patterns and their associated impacts are relatively new and thus in need of study. The case described here, reserving areas for the benefit of particular species, introduces a set of more detailed problems. Theoretical development of biological principles for conservation are still new in terrestrial protected areas (eg. Shafer, 1991), and most marine species are less well known than terrestrial species. Baseline research, as well as theory building are required, posing asignificant cost and time delay in initiating scientifically based design principles and management plans in the marine sphere. Nevertheless, reserves set aside without attention to scientific principles will be less able to fulfill the protection mandate, and may become a burden in the future when adjustments are necessitated by more critical examination.

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Part III
Synopsis

Conclusions and Summary

Report of the IVth World Parks Congress Workshop II.11: The science of conservation in the coastal zone

Chair: Dr. Tundi Agardy
Rapporteurs: Dr Wendy Craik and Paul Holthus

Section I: Summary

Workshop II.11 was the first in a succession of four meetings focusing on how to conceive and implement better marine protected areas and use them to practice more effective marine conservation on ever larger scales. The four workshops, in general terms, cover science, planning, operational management, and lessons to be learned from specific examples.

Approximately seventy participants from around the world attended the marine science workshop. Of these, close to 70% were applied or theoretical natural scientists, 5% social scientists, and 10% academics. An estimated 85% have had a direct role to play in the formation or management of at least one marine protected area.

The science workshop was designed to allow participants to hear presentations from six scientists representing divergent fields of interest and geographical foci. These included Drs Paul Dayton (Scripps Institution), Danny Elder (IUCN), Ian Dight (James Cook University), Phil Dearden (University of Victoria), Carleton Ray (University of Virginia) and Jack Sobel (Center for Marine Conservation). In the afternoon, participants heard about special projects in the Mediterranean by Dr Nicole Glineur (World Bank) and Australia (Great Barrier Reef Marine Park Authority) by Dr Wendy Craik. Discussions following all of these presentations were animated and constructive, and participants spent the bulk of the afternoon suggesting statements for the report and Caracas Action Plan.

Section II: Introduction to concepts

The general goal of this workshop was threefold: 1) to identify the kinds of science important to the design, planning, implementation, and long-term monitoring of effective multiple use marine protected areas; 2) to begin to translate that scientific information into a language both understandable and useful for planners and managers; 3) to generate clear and considered yet specific statements on how to create and maintain better marine and coastal protected areas.

Broadly speaking, the conclusions of the workshop relating to the third goal can be grouped in five categories. These categories roughly correspond to a chronologically-ordered set of steps describing the process by which science-based, ecosystematic marine protected areas should be planned and managed. They are:

A. How to identify the area of concern, recognising the geographically widespread linkages between marine and terrestrial habitats (eg. deciding how far up the watershed to focus management planning). This identification of the area of concern must be done with clearly defined management goals in mind. Whether these goals are biological, sociological, economic, or political, they must be specific to the area where the protected area is being planned.

B. How to identify ecologically important areas in order to conserve critical processes and ensure that the management of the protected area will be sustainable. In order to delimit critical areas for certain target species or core areas for habitat conservation, this process must utilise whatever information is available from the fields of physical and chemical oceanography, population dynamics and genetics, and ecology. Some of this information is likely to be conceptual and derived from state-of-the-art models, other data will be region-specific or local in nature.

C. How to actually delineate these areas for management, and make their boundaries widely recognisable to all users. This step involves translating theory into practice, and also involves feasibility investigations. Guidelines based on existing scientific information could help determine these boundaries.

D. How to manage core areas and buffer areas around these important focal areas. Although this is a management exercise that is based equally in science, economics, and sociology, the science is imperative to determine: 1) what processes are critical; and, 2) which processes can be conserved through management.

E. How to monitor progress to evaluate whether the original objectives are being met, to assess whether evolution of the landscape/seascapes (through rehabilitation or restoration) is moving in a positive direction, and to contribute to a network of protected areas utilising marine and coastal reference points to evaluate regional and global phenomena.

These are very general categories of action. More specific suggestions are listed in Section IV, organised according to the five general categories.

Another important consideration, perhaps the most important in successfully making marine protected areas more ecologically sustainable is ensuring that links among scientists and between scientists and managers are established and maintained. This involves effective two way communication between scientists and planners, scientists and managers, and among scientists and conservation biologists, fisheries scientists, oceanographers, economists, sociologists, political scientists, and terrestrial ecologists. Statements pertaining to this consideration are listed under a sixth subheading.

Section iii. Foci for conservation

Ecologically important marine areas deserving the strictest possible attention may be identified for one or more of the following roles:

1. to protect especially important areas for production that support a targeted suite of species of an ecosystem, such as feeding areas, breeding areas, sources of recruitment, and nursery areas;
2. to protect species-rich or particularly sensitive marine areas;
3. to protect important gene pools or specific "seed banks" of organisms;
4. to protect preserve populations of organisms at levels greater than theoretical minimum viable population sizes;
5. to provide control and testing areas for experimental research or for long-term monitoring to test the effects of management; or
6. to provide sites for assessing regional or global change phenomena.

Protection of these ecologically essential areas means focusing conservation/management on critical processes. This requires a physiological or functional, rather than a structural, view of marine conservation.

Marine protected areas exist as discretely defined focal points for conservation and cultural preservation in a larger, less-managed mosaic of landscapes and seascapes. As our planning and management improves and becomes more science-based, we are able to look beyond the boundaries of marine protected areas to the ocean and coastal systems at large. The role of science in both planning or managing marine protected areas and in developing larger scale ecologically sustainable ocean conservation is complex. Science has its entry points into more holistic marine protected area management in many places, some of which are enumerated below.

A. On defining the area of interest for conservation

* Understanding that marine environments should be managed comprehensively though integrated management planning, a range of methodologies should be employed for zoning or management.
* Natural regions should be defined (ie. large marine ecosystems) based on biophysical characteristics of the system targeted for conservation.
* The scientific community needs to apply the knowledge and theories of ecology, genetics, oceanography, hydrography, and conservation biology to define discrete management units. The boundaries of these units can then be modified according to socioeconomic and cultural factors to define sustainable use or biodiversity conservation objectives.
* In identifying sites for marine protected areas, scientific investigation and feasibility analyses should proceed in parallel, not sequentially. This site identification should seek out and document local/traditional knowledge.
* In order to identify a marine or coastal area needing management attention, we must ask

ourselves what we are trying to protect, and from what? Every marine protected area should have a well-defined operational objective or set of objectives, such as protecting a resource, a value, or a system. Operational objectives might be broadly classified in three categories: 1) protecting biological diversity; 2) demonstrating sustainable use; and 3) monitoring environmental change.

* The science conducted in support of marine protected area establishment, boundary setting, and monitoring needs to include social and economic sciences.
* The social sciences, especially anthropology and socio-geography, should be utilised to identify important areas to preserve. CNPPA should thus undertake a study on the ways traditional populations identify such focal areas and how they manage their impacts on them.
* Special attention should be given to those species that traverse, or are affected by factors that traverse, national boundaries -- in terms of both science and management.
* Given the nature of marine and coastal systems and the enormous threats they are under, multiple use, multi-objective protected areas should be a large as possible. Such scaling up does not necessarily imply that strictly protected sub-areas within the greater management regimes (see below) need also be large.
* New developments in the theory of size and shape of protected areas (the SLOSS -- single large or several small -- debate) should be carefully monitored for their applicability to marine protected area design.

B. On identifying foci for management (ie. critical or core areas)

* As full and as diversified a portfolio of methods as possible should be used to identify critical processes and where (and when) such critical processes occur. Such methods include, *inter alia*, physical and chemical oceanographic studies, biophysical modelling, remote sensing and GIS mapping, ecological studies, population genetics and dynamics analyses, and traditional knowledge. The main objective that all of these tools achieve, preferably in concert, is to define critical or focal areas within management units.
* The size, shape, and locate of harvest refugia, core areas, or critical areas should be determined experimentally -- starting with best guesses based on available data, scientific theory, and local knowledge.
* In designing core areas in shallow water tropical regions, special considerations should be made in protecting "source" reefs. Analogous, though less well-defined, situations exist in other marine systems.
* Problems of scaling and dynamics of identifying cores must be considered, keeping in mind that delineation of seasonal or moving cores is at least theoretically, if not always practically, possible.
* Substantial scientific effort should be directed at developing and testing tools for identifying critical processes and core areas that could easily be used in developing countries lacking sufficient resources to devote to science and for which existing time series data on marine areas are scant.
* IUCN should coordinate the development of a manual describing low-cost, low-tech methods for designing, implementing, and monitoring marine protected areas.

C. On delineating such core areas for management:

* Landscape and seascape ecology techniques for identifying core attributes and buffer processes should be utilised in all physical design and operational planning for marine protected areas.
* Further case studies that demonstrate successful identification of critical processes/areas and successful delineation of those areas for management must be documented.

D. On managing areas to safeguard against adverse damage to critical ecological processes:

* The ecological requirements of target species and the physiology of target ecosystems must form the basis for management. To this end, management must seek to control those direct and indirect human activities that most adversely impact population replenishment or impair ecosystem function.
* Not all detrimental anthropogenic impacts can be managed. Thus, scientists must work with planners to discuss feasibility of regulations, given not only human and financial constraints, but also system constraints that have their footing in the open nature of the ecosystems and the geographically large sale linkages between habitats and processes.
* In many marine systems, a core/buffer approach to management is important and should be utilised. However, the success of the core area will depend on the assurance that propagules for living components of the system will be able to reach and live in these strictly protected areas.
* For those areas where large scale commercial fishing (or even intense artisanal fishing) occurs, the management plan for the marine protected area may have to include aggressive, site- and season-specific control of fishing.
* Scientific information and approaches should be used not only in the design but in the long-term management of marine protected areas. Effective management will capitalise on a multi-disciplinary approach at all decision-making stages. Such involvement will improve necessary feedback between disciplines and provide additional motivation for scientists to become "conservation scientists".

E. On monitoring to assess management and contribute to studies of global or regional change:

* Long-term scientific monitoring of marine protected areas and their surroundings is vital to successful conservation and management. Governments and inter-governmental bodies should provide the resources necessary to allow long-term monitoring for: 1) biota and processes in protected areas; 2) the efficiency and course of management; 3) stresses on the protected system; 4) the status and trends in the regional and global environment; 5) the socioeconomic effect the protected area has on local and regional economies.
* The data collected from monitoring should be made freely available to all who have an interest in them, including government agencies, NGOs, industry, local communities, and conservationists. This data should be presented in a clear and understandable format.

- Marine protected areas managers should provide guidelines for visiting researchers/students to ensure that applied research undertaken in the marine protected area and its surroundings helps to achieve monitoring goals.
- The monitoring data should be standardised to allow for intra- and inter-regional comparisons and facilitation of training and education.

F. On facilitating two-way feedback between scientists and managers and links between scientists in many disciplines:

- Communication links between marine resource scientists and management at the international level must be opened up, including through: 1) publication of a directory of marine resource managers and scientists by region and area of expertise; 2) coordination of information exchange between scientists developing new paradigm for identifying critical areas; 3) establishment or support of a network for the transfer of information between scientists and managers; 4) development of a CNPPA-defined long-term strategy for marine protected areas planning that links with other IUCN Commission such as the Species Survival Commission and the Commission on Environmental Law.
- Results of research and monitoring should be framed to enhance public understanding and political will.

As stated in the beginning of this section, it is imperative that all marine protected area planning, including the identification of focal or critical areas, take place in the context of wider coastal zone and regional management considerations. To this end, it is important to treat the new generation of ecologically based and scientifically rigorous marine protected areas as small scale demonstration models, from which management should be scaled up to the regional, and eventually, perhaps, the global level.

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Founded in 1948, The World Conservation Union brings together States, government agencies and a diverse range of non-governmental organisations in a unique world partnership: over 800 members in all, spread across some 130 countries.

As a union, IUCN seeks to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable. A central secretariat coordinates the IUCN Programme and serves the Union membership, representing their views on the world stage and providing them with the strategies, services, scientific knowledge and technical support they need to achieve their goals. Through its six Commissions, IUCN draws together over 6000 expert volunteers in project teams and action groups, focusing in particular on species and biodiversity conservation and the management of habitats and natural resources. The Union has helped many countries to prepare National Conservation Strategies, and demonstrates the application of its knowledge through the field projects it supervises. Operations are increasingly decentralised and are carried forward by an expanding network of regional and country offices, located principally in developing countries.

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