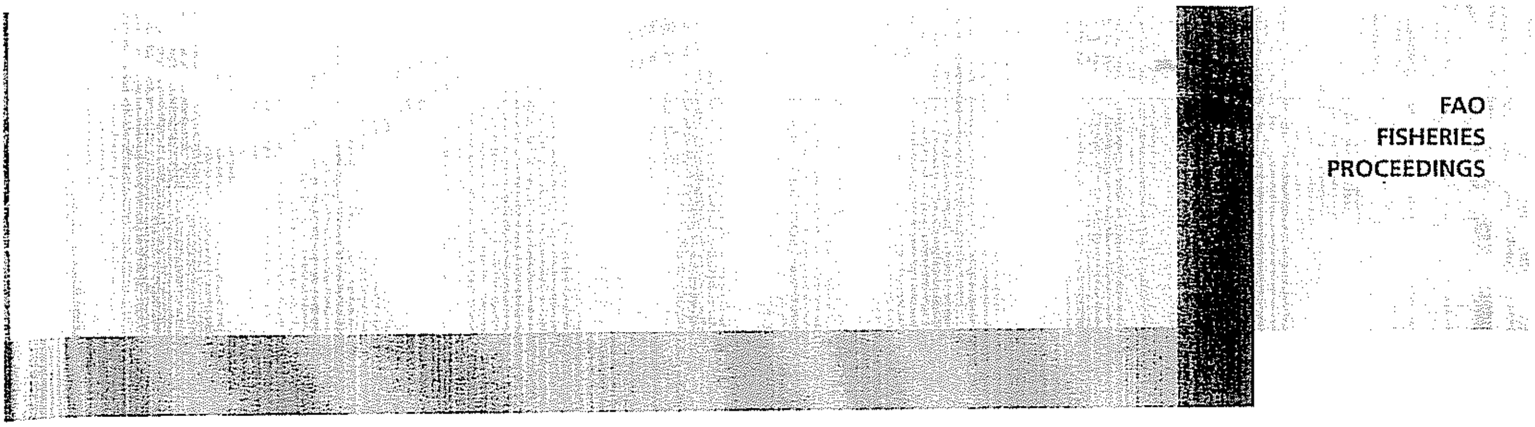

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# Marine protected areas (MPAs) as management tools to conserve seamount ecosystems

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## 1. INTRODUCTION

Understanding of the diversity and complexity of deep-sea ecosystems has developed rather slowly, principally because of the substantial difficulties in conducting research in such an extreme and inaccessible environment. Nevertheless, what was for a long time assumed to be a somewhat uniform, sparsely populated and constant environment is now increasingly recognized as a dynamic, biologically diverse and integral component of the biosphere. Initial reports of higher than expected species richness from the late 1960s have been confirmed only relatively recently by more extensive and quantitative surveys of deep-sea communities (Soetart, Haip and Vincx.1991, Etter and Grassle 1992, Grassle and Maciolek 1992, Rex *et al.* 1993).

Coupled with this general realization has come an understanding of the importance of the physical heterogeneity of the deep sea in contributing to overall diversity and species distributions. Of particular importance has been recognition of the significance of seamounts as foci for aggregation and/or higher productivity of diverse assemblages of deep-sea fauna (Wilson and Kaufmann 1987). Seamounts, rather loosely defined as geological structures rising at least 1 000 m above the seabed, have been variously described as reservoirs or "hotspots" of biodiversity, aggregation and productivity. What is clear, however, is that they represent, individually, and in combination, a vital component of the structure and processes of deep-sea ecosystems and their interactions with other biosphere compartments (Koslow *et al.* 2000, Roberts 2002).

Sadly, while our knowledge of deep-sea ecology has grown significantly over the past few decades, the technologies allowing commercial exploitation of these same environments, particularly for living resources, have developed much more rapidly (Clark and O'Driscoll 2003). This trend has been driven by a combination of increased pressure on fish stocks in shallower waters and the high prices commanded by some deepwater species. To date, most exploitation of seamount-associated fish stocks, especially of benthopelagic species such as orange roughy (*Hoplostethus atlanticus*), has been characterized by remarkably rapid development and subsequent depletion of newly discovered fishing grounds (Clark 1999, Roberts 2002, Smith 2003). This, in turn, has led to serial depletion of stocks in adjacent areas as effort has shifted in attempts to sustain catch. The task of quantifying the scale of impacts on non-target species, especially from intensive bottom trawling, has only recently begun (Koslow *et al.* 2000, Anderson and Clark 2003).

Few could argue that exploitation of benthopelagic fish over seamounts has been conducted in a sustainable manner so far. In the vast majority of cases, the diversity and vulnerability of seamount ecosystems have become apparent only after substantial, and possibly irreversible, damage has been done. We are faced with the prospect of having lost innumerable species before they are even discovered, both from waters under national jurisdiction and from the global commons. At the same time, seamount assemblages face a diversity of other threats or potential threats, including coral collection, seabed mineral mining, waste disposal and the unpredictable impacts of global climate change (Key 2002, Glover and Smith 2003, Johnston and Santillo 2004).

Together, these various threats raise the question as to whether, and if so how, seamounts may be exploited in a sustainable manner in the future. Can we preserve the integrity and diversity of these fragile geological and biological features while allowing continued commercial exploitation, for example through further refinements of stock assessments, fishing gear and fishery management plans? Or should the case now be made that the only sustainable option is the more precautionary one of closing seamounts to most, if not all, human activities? The answer depends largely on one's judgement of the values of ecosystems and one's perception of what constitutes sustainability.

## 2. SEAMOUNTS AS DIVERSE AND FRAGILE ECOSYSTEMS

Because of the manner in which seamounts interact with and modify oceanic currents, their presence is commonly associated with an increase in productivity and, or, biomass, both directly over the seamount and in the surrounding waters. Higher biomass may result from enhanced primary productivity through, e.g. upwelling and entrapment of nutrient rich waters (Mouriño *et al.* 2001) or from trapping of diurnally migrating planktonic organisms as they are advected across a seamount (Rogers 1994). It seems inevitable that the precise manner in which individual seamounts enhance productivity and production will be determined by a complexity of interacting factors influencing different seamounts to different degrees (Roff and Evans 2002, Trasvina-Castro *et al.* 2003). Likewise, the extent and mechanisms by which different components of deep-sea food webs are affected by, or even depend on, the physical presence of the seamount are also likely to be highly specific to location and local environmental conditions (Dower and Mackas 1996).

It has long been recognized that many fish species are often more abundant over seamounts than in the waters surrounding them. Seamounts are known to act as aggregation zones for commercially important species such as pelagic armourhead (*Pseudopentaceros wheeleri*), orange roughy (*Hoplostethus altanticus*), rockfish (*Sebastes* spp.) and oreos (especially *Allocyttus niger* and *Pseudocyttus maculatus*) (Clark and O'Driscoll 2003), a factor which has contributed substantially to the rapid expansion of seamount-associated deepwater fisheries. However, it is increasingly apparent that these commercially exploited species represent only a fraction of the total biomass and faunal diversity associated with seamounts.

Although research into community structure of seamount ecosystems remains limited, with most information arising from relatively few locations around the world, it is increasingly clear that even deepwater seamounts can support complex, biologically diverse and highly productive faunal communities. Because hard, rocky substrates characterize seamounts, they commonly support benthic communities dominated by suspension feeders such as corals, sea fans and sponges and so are markedly different from the fauna present in and on the surrounding soft sediments.

As Probert, McKnight and Grove (1997) note, much of the existing knowledge on the composition of seamount benthic communities to date is based on observations of bycatch in trawls for benthopelagic fish. Although such information has given an indication of the diversity of these faunal assemblages, it must be remembered that those species recovered unintentionally in commercial trawls may represent only a fraction of those present on the seafloor (Anderson and Clark 2003). The relatively few scientific surveys that have been conducted on deepwater seamounts have generally revealed hundreds of species of benthic and benthopelagic fauna with an especially diverse invertebrate community. For example, surveys of 14 of the Tasmanian seamounts, located 170 km south of Hobart, reported a total of 279 species, 242 of which were invertebrate species and the remaining 37 fish species (Commonwealth of Australia 2002a). Similarly, a survey of just four seamounts on the Lord Howe Rise east of the Australian mainland revealed more than 100 species (Commonwealth of Australia 2002b). At the same time, there is increasing evidence that seamounts along with other distinctive geological features of the ocean floor can act as important aggregation zones for pelagic top predators, including tuna and sharks (Worm, Lotze and Myers 2003), although the efficiency of energy transfer from the benthic to the pelagic community over seamounts remains largely unknown (Commonwealth of Australia 2002a).

A characteristic of many deep-sea benthic and benthopelagic organisms is their relatively long life-histories, including lengthy times to maturity. These highly "*K*-selected" life histories are perhaps best described for some of the commonly exploited fish species. For example, the orange roughy is able to live well in excess of 100 years, reaching sexual maturity only after 20–30 years (Tracey and Horn 1999). Oreos, another important component of total deepwater catches in New Zealand (especially over the southern Chatham Rise), are also long-lived, with maximum ages varying from 86 years for *P. maculatus* to 150 years for *A. nigra* (Smith 2003). Some rockfish (*Sebastes* spp.) have been estimated to be approximately 200 years old (Roberts 2002). Periodic, or even sporadic, recruitment may also be a common feature (Koslow *et al.* 2000), further reducing resilience to fishing mortality or other major disturbances.

Little is known about the life histories and population age structures of most of the other benthopelagic fish which aggregate over seamounts, although it is reasonable to expect that slow growth, late maturity and relatively long life are characteristics common to many deepwater fish species. In terms of invertebrates, the hard corals and sponges, which typify many of the Pacific seamounts studied to date are likely also to be long-lived and therefore, highly sensitive to disturbance. Although few empirical data are available concerning age structures and growth rates of deepwater black and gorgonian corals, it is thought that the larger colonies on relatively undisturbed seamounts may be several hundreds of years old (Smith 2003).

Seamount communities as well as representing local "hotspots" of biodiversity also appear to demonstrate a remarkably high degree of endemism, especially among their invertebrate fauna. In one of the earliest reviews encompassing 92 seamounts, Wilson and Kaufmann (1987) estimated that an average of around 15 percent of species may be restricted to individual seamounts. More recent studies have suggested even higher proportions of endemic species. For example, Richer de Forges, Koslow and Poore (2000) reported that between 29 and 34 percent of a total of 850 macro- and megafaunal species found on seamounts in the Tasman Sea and southeast Coral Sea (including the Norfolk Ridge and Lord Howe Rise seamounts) were "new to science" and possibly, endemic to individual seamounts or ridges.

Of the 242 invertebrate forms found on the Tasmanian seamounts, only around one third have so far been identified to species level, of which as many as 20 have not previously been found in Australian waters. Of the remaining 168 species, 139 have since been identified to genus level and, of these, it is thought that more than 50 may be species previously unrecorded anywhere in the world (including representatives of seven entirely new genera). Even for the fish species recorded, as many as one third of all species, and around half of all those occupying the deeper zones of the Tasmanian seamounts, are new to Australia or previously undescribed (Commonwealth of Australia 2002a). On the Lord Howe Rise, an area well noted for its high marine biodiversity at shallower depths, approximately 30 percent of species from deepwater seamount habitats appear to have been recorded for the first time (Commonwealth of Australia 2002b). Diversity and endemism on the seamounts of the Norfolk Ridge system further east from the Lord Howe Rise may be even higher, with as many as 17 new genera being recorded (Richer de Forges, Koslow and Poore 2000).

Moreover, in contrast to the significant overlap in species composition associated with deepwater soft sediment substrates over the Tasman and Southeast Coral Sea region, comparison of faunal assemblages from the Tasmanian and Lord Howe Rise seamounts indicates that there are no species common to both systems (Richer de Forges, Koslow and Poore 2000). Such findings suggest strongly that the geographical separation of these isolated and distinctive habitats can also result in a high degree of ecological and genetic isolation. This is undoubtedly most pronounced among those invertebrate species with relatively limited ranges of larval dispersal. For example, within the Azores seamounts system, distances of between 100 and 200 km appear sufficient to prevent the spread of larvae and egg capsules for some gastropod molluscs (Gofas 2002). Nevertheless, some localised genetic differentiation is also apparent in certain deep-sea benthopelagic fish species, even those apparently showing worldwide distribution. Hence, whereas genetic homogeneity appears characteristic for species such as pelagic armourhead (*P. wheeleri*) and smooth and black oreos (*P. maculatus* and *A. niger* respectively) (Smith 2003), genetic differentiation has been detected in some geographically isolated populations of the orange roughy (Smolenski, Ovenden and White 1993).

In summary, available evidence indicates that seamounts show high levels of biodiversity, are characterized by numerous characteristic species that are long-lived and slow to mature and may well support faunal assemblages with degrees of endemism unprecedented to science for the marine environment. Taken together, these characteristics imply that seamount ecosystems are likely to be particularly sensitive to, and slow to recover from, disturbances of any kind. Coupled to this is the important caveat that, despite recent advances in research, we still understand remarkably little even of the structure of seamount ecosystems, less still their dynamics and interactions with surrounding waters. Irrespective then of whether the high rate of identification of "new" species is a reflection of true endemism or an artefact of the small proportion of global seamount habitat so far surveyed, the sheer number of such new species, and even genera, that have come to light in recent years must surely highlight the intrinsic value in preserving these ecosystems.

## 3. THREATS TO SEAMOUNT ECOSYSTEMS

### 3.1 Seamounts effects

Because of the combined attributes of high biodiversity and sensitivity to adverse impacts, there is growing recognition of the need for protective measures for seamount ecosystems. At the same time, emerging evidence of the speed at which long-established seamount ecosystems are being profoundly impacted by human exploitation is serving to highlight the urgency with which such measures must be imposed. It is likely that seamounts and other such geologically and ecologically distinct deep-sea features will respond differently, perhaps uniquely, to the diversity of anthropogenic activities facing deepwater ecosystems now and in the future compared to the soft sediment communities typifying the majority of the deep-ocean area (Glover and Smith 2003).

### 3.2 Fishing

Among the various threats facing seamounts, undoubtedly the most immediate and by far the most extensively damaging to date has been deep-sea fishing, especially bottom trawling.

In contrast to coastal and shelf fisheries, deepwater fisheries over seamounts are a relatively recent development, made possible by advances in vessel design, trawl gear and equipment enabling more accurate mapping of the seafloor and location of fish aggregations. During the last few decades, interest in exploitation of seamount-associated species has grown markedly. Ironically, the characteristic of such populations that yields the high catches per unit effort necessary to make deep-sea fishing economically viable, namely the dense aggregations of the most important commercial species, inevitably results in overexploitation of these populations within remarkably short time scales. For example, intensive fishing of stocks of pelagic armourhead over the Pacific seamounts northwest of Hawaii led to their commercial extinction in less than 20 years (Roberts 2002).

Developments in the New Zealand orange roughy fisheries illustrate a typical pattern of rapid development leading to overexploitation and the serial depletion and collapse of stocks (Clark *et al.* 2000, Clark 2001, Smith 2003). These fisheries, target orange roughy but also take a valuable bycatch of oreos (especially *P. maculatus*) and have been established for 20–30 years. During this time, fishing effort and total catch of orange roughy has focused increasingly on populations aggregating over seamounts such that by 2000 approximately 80 percent of such structures within the appropriate depth range for orange roughy had been fished to some extent (Clark and O'Driscoll 2003). Total catch for seamount fisheries in New Zealand waters stands at approximately 40 000–45 000 t a year, a high proportion of which is sustained by the orange roughy fisheries.

In the late 1970s, only one seamount in New Zealand waters had been documented to have been affected by more than 10 tows (within 10 km of its centre point); by 1999–2000 this had increased to 248 (217 of which were fished for orange roughy), with more than 100 seamounts fished in a typical year. Much of this increase occurred in the early 1990s and resulted from a combination of improved technology and declining catches on other seamounts (Clark and O'Driscoll 2003).

Typically, newly discovered stocks have been fished down to around 15–30 percent of the estimated virgin biomass within only 5–10 years of the start of exploitation (Koslow *et al.* 2000). Despite drastic reductions in total allowable catches (TACs) in many regions of Australia and New Zealand, these have all too often been incapable of preventing rapid stock decline. Although there is some evidence that orange roughy catches over certain seamounts are "relatively stable" (Clark 2001), or even that populations are beginning to increase, the periods over which observations are available are much shorter than the life-histories of the fish themselves, such that any trends must be interpreted with a high degree of caution. Moreover, even if some increases in catch have been reported, the possibility remains that such increases have resulted not from a genuine "recovery" of orange roughy populations but merely from juveniles, which previously escaped trawls, reaching sizes that render them vulnerable to capture. The irony is that in the many years, if not decades, it will take for the underlying population dynamics to be confirmed, depletion of mature individuals to levels below those necessary to sustain a population could easily occur.

Of course, the effects of deep-sea fishing are not restricted to the target species themselves, nor even to those species commonly landed as bycatch, although it is these impacts which have in the past been most visible and, because of their commercial consequences, subject to most management interest. As noted above, damage to non-target organisms in the benthic and benthopelagic zones from the passage of bottom trawls is of particular concern, especially given the high diversity, low growth rates and fragility of many sessile deepwater species.

The trawl gear typically employed in orange roughy fisheries is large and heavy and is designed to withstand being towed across the rough terrain characteristic of seamounts. Its deployment directly on the seafloor, close to which orange roughy commonly aggregate, inevitably leads not only to bycatch of other demersal species but also to extensive damage to sessile invertebrates, including corals, within the trawled areas (Anderson and Clark 2003). In addition, secondary but more widespread impacts may be expected from resuspension of areas of softer substrate by the passage of the trawl gear (Collie, Escanero and Valentine 1997) though the significance of any such impacts on seamounts have not yet been assessed.

Anderson and Clark (2003) provide the first comprehensive overview of the scale and diversity of bycatch in seamount fisheries based on observer data collected from New Zealand vessels fishing orange roughy on the South Tasman Rise between November 1998 and September 2000. Although oreo species make up the majority of the bycatch (and a total of 29 percent of the total catch), various corals, at around 150 t over the period, accounted for around 22 percent of bycatch and more than 8 percent of the total weight of material captured in the trawls. Observer reports indicate that for a single trawl to bring up between 1 and 15 t of coral is not uncommon. There is some evidence that similar or even higher quantities of coral per trawl have been recorded by other operators in this region (Anderson and Clark 2003). Although data are almost absent from other such fisheries, there is every reason to expect that high levels of coral bycatch, and the resultant long-term damage to the benthic community, are inevitable consequences of bottom trawling on seamounts throughout the world.

Studies of trawl damage on the Tasmanian seamounts recorded much higher proportions of bare rock in heavily trawled areas (up to 95 percent) than in comparable "unimpacted" areas of seamount (10 percent bare rock) (Koslow *et al.* 2000, 2001). Dredge samples from fished areas recovered 59 percent fewer species and little over half the biomass recovered from equivalent samples collected in unfished areas.

More recent observations on Ritchie seamount, a structure located off the east coast of New Zealand's North Island and heavily fished for orange roughy, revealed prominent "gouges" associated with the passage of trawl doors and associated equipment (Clark and O'Driscoll 2003) with approximately 50 percent of the total seamount area impacted to some degree.

Other surveys of heavily and less heavily fished seamounts in New Zealand waters reveal marked differences in the quality and integrity of the benthos. On the heavily fished "Graveyard" and "Morgue" seamounts, as many as 29 and 17 percent of survey photographs respectively indicated significant fishery-related impacts, compared to only 1 to 5 percent on the less intensively fished "Gothic" and "Diabolical" seamounts respectively. Moreover, whereas frequent patches of 100 percent standing coral cover were recorded on these latter two seamounts, occurrence of coral on the heavily fished seamounts did not exceed 2–3 percent cover in any of the locations surveyed (Clark and O'Driscoll 2003).

Based on the relatively slow growth rates observed for deep-sea corals and other sedentary organisms, recovery of severely damaged areas may be expected to take decades or even centuries (Jones 1992). Moreover, deepwater corals provide a complex and diverse array of refugia for other seamount-dwelling organisms (Smith 2003), which can therefore also suffer both immediate direct damage and suffer the longer-term impacts of habitat loss as a result of the passage of the heavy trawl gear. Although there is evidence that some profound changes in deep-sea community structure can occur over long timescales as a result of natural events and processes (Steele 1998), the rapidity and severity of changes resulting from human activities such as intensive bottom trawling are likely to far surpass any such natural fluctuations and trends. Their ultimate effects and, indeed, the ability of complex and fragile benthic communities to recover fully even over long periods of time remains to be seen.

### 3.3 Other human activities

Without doubt, the most direct and immediate human affects on seamount ecosystems – overfishing and destructive fishing techniques – are by no means the only anthropogenic activities and changes which threaten seamounts in the medium to longer term. Aside from deep-sea fishing, Glover and Smith (2003) list the principle threats facing the deep sea in general as

- disposal of wastes (structures, radioactive wastes, munitions and carbon dioxide)
- oil and gas extraction
- marine mineral extraction and
- climate change.

Particular attention is drawn to growing pressure for deep-sea carbon dioxide disposal, which could have profound and unpredictable impacts on biogeochemical cycles. Another is mineral extraction, particularly manganese nodule mining, highlighted as "one of the most significant conservation challenges in the deep sea" on the basis of the total areal extent ultimately likely to be impacted (Glover and Smith 2003). Other authors have noted a similar array of threats with more specific reference to their potential impacts on seamount ecosystems (Key 2002, Johnston and Santillo 2004).

Proposals to recover mineral resources such as polymetallic nodules and crusts from the deep sea are likely to be a commercial reality only some time into the future but are already under active consideration by the International Seabed Authority (ISA 2002), the body to which jurisdiction over the deep-sea bed of the global commons was assigned under the United Nations Convention on Law of the Sea (LOSC 1982). So far, work within the ISA has focused primarily on the development of regulations concerning the exploitation of polymetallic nodules. Of greater significance to seamount ecosystems, however, may be the potential exploitation of ferromanganese crusts, features which are not uncommonly located adjacent to, or even on the slopes of, seamounts (Hein *et al.* 2000). At this early stage, prediction of the nature and scale of impacts is inevitably a highly uncertain exercise, although significant near and far field effects may be anticipated. These may include physical damage in the immediate vicinity of the mining operation (Thiel 2001), secondary impacts from resuspended sediment on the benthic and pelagic communities down-current from these operations (Koslow 2002) and, even further afield, settlement of fine particulates and other wastes arising from surface processing operations (Rolinski, Segschneider and Sündermann 2001). As Halfar and Fujita (2002) stress, the implementation of management programmes incorporating a high degree of precaution will be essential from the outset of deep-sea mineral exploitation.

The scale of threats presented to seamount ecosystems by these and other potential human activities in the deep sea (oil and gas exploration and exploitation, $CO_2$ disposal, etc.) will depend critically on the proximity of the activities to seamounts and the direction and strength of ocean currents. Nevertheless, prediction and assessment of impacts are destined to remain highly uncertain, not least because of the lack of knowledge regarding, and difficulties in researching, deep-sea ecosystems and their responses to perturbation. While there is now widespread acceptance that the deep-sea, pelagic and atmospheric components of the biosphere are closely interlinked over intermediate and long-term timescales, predicting even the direction of possible impacts of human intervention, let alone their magnitude, remains a speculative activity.

Further, the extent to which the pressures of fishing mortality and disturbance contribute to increased vulnerability of target species to other environmental stresses, both natural and anthropogenic (Lauck *et al.* 1998), is not known, although once again such indirect impacts are likely to be more pronounced in low-fecundity, slow-growing deepwater species. The likelihood of adverse impacts arising from global climate change, even that to which we are already committed through historic emissions, only increases the necessity to minimize as far as possible the magnitude of other stresses within our control.

## 4. APPROACHES TO THE CONSERVATION OF SEAMOUNT ECOSYSTEMS

### 4.1 Extent of the challenge

It is evident then that deep-sea ecosystems, far from being isolated from local and global environmental changes and human pressures, are likely to be highly sensitive to stresses in ways that will be difficult to predict and which may result in serious or irreversible loss of habitat ad biodiversity. Seamount communities, while representing just one component of the deep-sea environment, nevertheless deserve special consideration because of their particularly high ecological value, vulnerability and the ongoing nature of widespread and intensive human exploitation.

The extensive damage already caused to many seamount ecosystems through overfishing and destructive fishing practices has rightly attracted a high level of concern from the scientific community and, increasingly, from policy-makers. The recent opening statement on protecting deep-sea coral and sponge ecosystems, initiated by the Marine Conservation Biology Institute and so far signed by more that 1 000 scientists is a clear illustration of this level of concern (MCBI 2004). This statement draws attention to the "unprecedented damage" being done to benthic communities on continental plateaus, slopes and seamounts, and, noting the overwhelming contribution of bottom trawling to this damage, calls upon all states to introduce prohibitions on this activity in the vicinity of coral stands and similar structures within their EEZs. Further, the statement urges the United Nations to establish a moratorium on bottom trawling throughout the high seas.

Given the history of bottom-trawl impacts on seamounts, this radical approach has considerable merit and substantial conservation benefits over more traditional fishery management responses. For example, reductions in TAC or gear restrictions may provide some level of enhanced protection for target and some non-target species, but it will remain almost impossible, especially in deepwater environments, to determine whether these measures are really "conservative" enough, or even whether they are effective at all in conserving the integrity of seamount ecosystems. As Lauck *et al.* (1998) noted in a more general context, "coastal state fishery management programmes have proven in far too many instances, to be seriously deficient". For target species themselves, lack of good data on levels and patterns of recruitment is a major source of uncertainty in current stock assessments (Clark 1999). The success of any management strategy that allows continued exploitation of living resources over seamounts will, therefore, inevitably be subject to the undeterminable errors and biases that are inherent in management models, as well as to the substantial uncertainties in effort and catch estimates. This alone is a major limitation to achieving sustainability, even from the limited perspective of single species conservation. Add in the collateral damage to the benthos, which seems an unavoidable consequence of bottom trawling over seamounts, and any hope of achieving sustainability by any reasonable definition disappears.

Even the precautionary approach to fishing developed by Myers and Mertz (1998), in particular the assurance that fish should be permitted to spawn at least once before they are subject to fishing pressure, may have limited applicability to conservation of seamount biodiversity, not least because it relies heavily on the effective selectivity of fishing gear. Given the markedly long life-histories and late maturity of many deepwater demersal fish species, it seems unlikely that any gear could be sufficiently selective to ensure that this management principle was not violated in the case of, for example, orange roughy fisheries. Bottom trawling on seamounts is by no means a highly-controlled process and, given that knowledge of the population structure and ecology of most deepwater organisms remains limited, it is difficult to see how such a "spawn-at-least-once" policy could ever be reliably applied to seamount-associated species. Moreover, while potentially introducing an element of precaution in relation to the target species of a fishery, the approach of Myers and Mertz (1998), taken in isolation, once again fails to address the collateral impacts of bycatch and damage to sedentary benthic organisms.

The complete closure of selected seamounts to bottom trawling (or, indeed, all forms of fishing) may appear as a radical and, perhaps, somewhat blunt approach but it is neither an unprecedented measure nor one which is unjustified in both scientific and management terms. For example, formal measures closing 19 seamounts to bottom trawling and dredging within New Zealand waters were introduced by the New Zealand Ministry of Fisheries in 2000 and came into effect in May 2001 (Clark and O'Driscol 2003). Although they represent only a fraction of the total number (and area) of seamounts in the region, the sites were selected to give as broad a biogeographic range as possible with the objective to confer at least some protection upon an equally wide representation of fauna. All but one of the seamounts covered by the closure had not been previously fished; Morgue Seamount was included to allow monitoring of long-term recolonization of an area heavily affected by previous bottom trawling operations. As Smith (2003) notes, the immense difficulties anticipated in monitoring gear restrictions and policing partial closures of seamounts contributed to the decision of the Ministry to opt for closure of the 19 representative seamounts to all forms of fishing activity.

Although significant, both in terms of the level of protection conferred and the precautionary basis on which closures were assigned, it must be remembered that the 19 seamounts covered by this order represent only a small fraction of the total number of such features even within New Zealand's EEZ. Therefore, while these closed areas will undoubtedly contribute something to the conservation of deep-sea biodiversity in the region, exploration and exploitation of fisheries over the majority of New Zealand's seamounts looks set to continue. The same concerns relate to the rather limited extent of fully closed seamount areas incorporated within conservation management systems in operation in other coastal states (see below), though it must be recognized that the mere existence of Australia's National Representative System of Marine Protected Areas (NRSMPA) is a substantial asset given the near absence of any effective measures or strategies in the waters of most coastal states (ANZECC 1998).

In short, what is currently missing is a much more comprehensive international or even global approach to the protection of deep-sea ecosystems, including seamounts, from the full spectrum of human activities and impacts. Whereas a moratorium on the most damaging fishing practices would clearly be a welcome and highly progressive step, this in itself is unlikely to provide the level of security or breadth of coverage required to protect deep-sea biodiversity in perpetuity. As such, a moratorium can be seen as a "necessary but not sufficient" management response to the totality of threats facing deep-sea biodiversity. It is vital that, alongside such immediate measures, much greater attention is given to the development of effective and integrated systems of marine protected areas (MPAs) which encompass *inter alia* sufficient representation of seamounts from all distinct biogeographic zones.

### 4.2 Application of the Marine Protected Area concept to seamounts

Marine protected areas are increasingly seen as valuable, or even essential, components of strategies aimed at the conservation and sustainable management of the marine environment. Lauck *et al.* (1998) point to the "irreducible scientific uncertainty pertaining to marine ecosystems", which, coupled with the problems of controlling catches and minimising bycatches, provides substantial justification for the emplacement of large-scale MPAs as a key component of future management regimes. In addition to the obvious protection conferred on biodiversity, MPAs can provide for a simple management regime within the protected areas as well as acting as a buffer against the impacts of possible failures of fishery management measures outside these areas.

Although there are a diversity of definitions emphasising different aspects of the concept, most capture the same essential elements as the widely recognized IUCN definition of a protected area:

> *"an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means"* (IUCN 1994).

In outlining the mechanisms for the establishment of Australia's National Representative System of MPAs, the ANZECC MPA Task Force provided a more specific goal:

> *"to establish and manage a comprehensive, adequate and representative system of MPAs to contribute to the long-term viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels"* (ANZECC 1998).

Of particular importance are the facts that MPAs established under the NRSMPA programme are established with the conservation of biodiversity as their primary goal and that their status is protected under law. Furthermore, the requirements for comprehensiveness, representivity and adequacy when establishing individual MPAs are vital to the success of the system in meeting their primary objective.

It is clear that MPAs are more a management concept than a sharply defined and universally applicable tool; clearly they need to be defined, protected and monitored in a manner that is appropriate and effective in relation to the specific environments in which they are located and should aim at optimization over time as their effectiveness is assessed. In recognition of the differing levels of human intervention that can be tolerated by various biogeographic zones and components of the marine environment, IUCN Guidelines (1994) provide for six categories of protected area, ranging from Category I (including Ia – "strict nature reserve", and Ib – "wilderness area"), representing areas fully protected from all activities, to Category VI ("managed resource protected areas"), which allow for "sustainable flow of natural products and services to meet community needs". In practice, the degree of actual protection conferred will depend heavily on the commitment to, and effectiveness of, management of the MPA as well as the suitability of the Category designation to the management goal. Moreover, the areas need to be large, integrated and representative enough to provide effective refuge to threatened species (Parrish 1999, Mangel 2000).

It is estimated that there are currently about 1 300 MPAs designated worldwide (Boersma and Parrish 1999), albeit representing a wide diversity of management goals and permitted activities. Their effectiveness varies, as may be expected, though most can be seen to have provided some significant positive benefits in terms of diversity and biomass of both commercially important and non-commercial species at least within the boundaries of the reserves (e.g. Jennings, Marshall and Polunin 1996, Kelly *et al.* 2000, Halpern and Warner 2002). Application of the concept to migratory species has also delivered some tangible improvements in conservation (Guenette, Lauck and Clark 1998). Halpern (2003) provides a useful review based on studies of 76 MPAs.

Despite the increasing rate of designating MPAs across the globe, the total area of the marine environment covered by at least some degree of protection remains woefully small and inadequate to protect representatives of even the most sensitive marine ecosystems across all biogeographic zones. Moreover, it is specifically the severe lack of marine protected areas that are effectively closed to all damaging or potentially damaging human activities (so-called "wilderness", "fully protected" or "sanctuary" areas) that gives the greatest cause for concern (Dayton *et al.* 2000).

The UK Government's Environment, Food and Rural Affairs Committee recently concluded (House of Commons 2004) that *"The current patchwork of national, European and international laws, Directives and agreements is not fully capable of providing proper protection for the marine environment in the 21st century, subject* *as it is to increasing commercial exploitation"*. Similar concerns have led to a number of political initiatives at national and international levels in recent years aimed at greatly extending and integrating systems of MPAs. At the global level, one significant outcome of the World Summit on Sustainable Development (UN 2002) was a common commitment to develop by 2012 "representative networks" of MPAs to begin to address the rapid depletion of marine biodiversity. At a regional level, the 2003 Joint Ministerial Meeting of the OSPAR and Helsinki Commissions (protecting the North East Atlantic and the Baltic regions respectively) agreed to develop "by 2010 a joint network of well-managed marine protected areas" (OSPAR/HELCOM 2003).

On the basis of the special concerns for seamounts outlined in previous sections of this paper, it seems reasonable to argue strongly that any coordinated development of MPAs must incorporate a substantial number of seamounts and seamounts types. Indeed, this is a necessary condition for the effectiveness of these developments to meet their conservation goals. This point is also strongly made in the joint scientific statement referred to earlier

> *"...we urge [individual nations and states] to establish effective, representative networks of marine protected areas that include deep-sea coral and sponge communities" (MCBI 2004).*

Further, given the particular sensitivity of such communities to long-term, potentially irreversible damage from all forms of human exploitation, it seems reasonable that these structures should also receive the most protective status (equivalent to IUCN Category I) within MPA designations. Once again, there is some precedent for this within the few examples of existing MPAs that encompass seamounts.

## 4.3 MPAs incorporating seamounts

### *4.3.1 Existing practices*

Those seamounts currently afforded protection under national jurisdiction represent only a fraction of the many thousands known to exist worldwide. Nevertheless, the significance of these isolated examples, concentrated particularly in the waters around Australia and New Zealand, must not be underestimated, from the perspective of both the degree of local protection they provide and the example they can set for similar initiatives worldwide.

Important examples of MPAs incorporating seamounts can be found in US waters (*e.g.* Cordell Bank, a relatively shallow structure of the Californian coast), the Caribbean (Saba Marine Park in the Netherlands Antilles, incorporating two seamounts) and even in Antarctica (Port Foster Site of Special Scientific Interest, which includes a sub-sea volcanic caldera) (Roberts 2002). However, among the most widely known are those in Australian waters, including the Tasmanian Seamounts Marine Reserve and the Lord Howe Island Marine Park and the much discussed Bowie Seamount in Canadian national waters.

### *4.3.2 The Tasmanian Seamounts Marine Reserve*

The Tasmanian Seamounts consist of approximately 70 structures located 170 km south of Hobart and rising to between 1940 and 660 m of the sea surface. As noted in Section 2, those seamounts studied indicate remarkably high diversity and endemism, with benthic fauna dominated by stands of the coral *Sollenosmilla variabilis* or, in deep areas, by sea urchins.

Following initial reports of high benthic biodiversity in the mid 1990s, an interim closure of an area of 370 $km^{-2}$ to fishing was agreed to. This was followed in 1999 by the designation of the marine reserve, encompassing 15 of the seamounts (primarily the deeper structures) and representing approximately 20 percent of the total area of the Tasmanian Seamounts region. This selection was considered a representative sample of seamount diversity in the area (Commonwealth of Australia 2002a), although it must be noted that this decision was necessarily taken in the face of high uncertainty.

The primary objective of the reserve is "to protect the unique and vulnerable benthic communities of the seamounts" (Commonwealth of Australia 2002a). The Tasmanian Seamounts reserve is divided into two zones based for management purposes exclusively on depth. On the basis of an assessment that pelagic fisheries over the seamounts were not the primary concern with respect to conserving biodiversity, and that the area did not represent a spawning ground for key migratory species, the waters down to a depth of 500 m are administered as a "managed resource protected area" (equivalent to IUCN Category IV). Below 500 m, the seamounts are managed as a strict nature reserve (IUCN Category Ia) and all fishing and other forms of human exploitation are prohibited. Importantly, the exclusion zone extends to 100 m beneath the seabed to guard against any future interests in mineral extraction.

### *4.3.3 Lord Howe Island Marine Park*

The seabed ridge structure which breaks the surface at Lord Howe Island and Ball's Pyramid runs roughly parallel to the coast of Australia, 700 km northeast of Sydney. The Park incorporates all elements of the marine environment from the shallows down to a depth of approximately 1800 m, including a number of seamounts and similar structures. Once again this area is recognized as an area of immense diversity and high conservation value (Commonwealth of Australia 2002b).

The existing 12 nm exclusion zone for pelagic fishing (for tuna, billfish and squid) and 25 nm exclusion zone for bottom trawling date from 1993. In practice, bottom trawling over the steep and rugged slopes of much of the rise has been limited by lack of technical feasibility, although there have been some exploratory deepwater fisheries in the past, particularly for orange roughy. There are not thought to be any significant mineral or oil reserves in the immediate vicinity of the rise.

The primary objective of the reserve is "to protect the seamount system ad its conservation values associated with marine biodiversity, habitats and ecological processes" though secondary goals of supporting tourism and certain traditions of the local community are also defined. The majority of the Park is assigned IUCN Category IV, such that some commercial activities other than mining may be permitted, subject to conditions including that these activities do not undermine the primary conservation objective. To this end, both trawling and long-lining are prohibited. In addition, two areas are set aside as Category Ia Sanctuary Zones, designed to protect a representative proportion of the shelf, slope and deepwater environment from all human activities and, in turn, to provide a baseline for research and monitoring.

### *4.3.4 The Bowie Seamount*

The Bowie Seamount forms part of the Canadian Government's commitment to develop an MPA system for Pacific coastal waters (Governments of Canada and British Columbia 1998). The seamount is located 180 km west of the Queen Charlotte Islands and rises from the seafloor at 3 100 m to within 25 m of the sea surface. It is recognized as a site of high biological diversity and productivity and, since the 1980s, has supported commercial fisheries for sablefish (*Anoplopoma fimbria*) and rockfish (*Sebastes* spp.) (Fisheries and Oceans Canada 2001).

MPA status was assigned to the Bowie Seamount at the end of 1998 and the area of interest has subsequently expanded to incorporate the Hodgkins and Davidson seamounts to the northwest. However, since 1998 progress towards development and emplacement of the associated management plan has been relatively slow. The Bowie Seamount MPA differs significantly from those in Australian waters in its explicit recognition of "the conservation and protection of commercial and non-commercial fisheries of the area" as one of the three main management objectives. It may well be, therefore, that some considerable degree of human intervention and, inevitably, damage will ultimately be tolerated by the terms of the MPA. The extent to which this may compromise the other primary objectives of conservation and protection of habitats and biodiversity remains to be seen. At present, three options are under consideration for designation of parts of the MPA as no-take "harvest refugia", ranging from an area covering only the Bowie Seamount itself to full protection for all three seamounts in the immediate vicinity (WWF 2003).

### *4.3.5 New Zealand seamount closures*

These have been discussed in Section 4.1. It should be noted that the New Zealand closures are a specific and free-standing measure, rather than forming part of a broader programme of MPA designation. Nevertheless, the significance of the closures is in their regulatory simplicity and the immediacy in affording protection from the damaging effects of fishing. Their establishment in this manner does not preclude a subsequent incorporation into such a programme in the future. Indeed, it is to be hoped that such measures can swiftly be extended to encompass a much larger proportion of seamounts in New Zealand waters, whether pristine or previously fished. Otherwise there is a danger that these 19 closures will provide little more than token protection for seamount biodiversity in the region.

## 5. MEETING THE CHALLENGES: PROTECTING SEAMOUNT BIODIVERSITY

It is easy to point to the deep-sea, and to seamount ecosystems specifically, and conclude either that the MPA concept simply cannot be applied to such systems in any meaningful way or, at least, that any such designation will need to await much more detailed description and understanding of ecosystem structure and dynamics. It is hoped that the positive examples of seamount MPAs already in operation will increasingly serve to dispel the first criticism. The dilemma regarding the second assertion is that at current rates of human exploitation, biodiversity is undoubtedly being lost at a far greater rate than it is being discovered.

The ability to define specific objectives with respect to MPAs at the time of their establishment is seen as an important guiding principle for the development of MPA systems (see e.g. Fogarty, Bohnsack and Dayton 2000). Inevitably, however, such ambition has to be tempered with the limitations to understanding of the system which the MPA is being designed to protect. Delaying the designation until such time as the size, depth range and management regime can be fully optimized is unlikely to be an option.

In such cases, which may be encountered frequently in the case of seamounts, it may be necessary to accept in the first instance a relatively broad management objective, such as those set for the Tasmanian and Lord Howe Seamounts, in order to apply precautionary measures in advance of obtaining detailed descriptions of community structure and dynamics. It is worthy to note that relatively little was known about the fauna of most of the 19 seamounts closed to fishing by the New Zealand government in 2001; rather it was hoped that the habitats and specific fauna captured by these measures would be representative of the biogeographic diversity of New Zealand seamounts (Clark and O'Driscoll 2003). Therefore, although described by some as a "stab in the dark", acting to protect these communities in advance of a full description of what would be protected could clearly be justified given the rapid development of the fishery.

As Lauck *et al.* (1998) stress, an "optimal" location, size and set of ecological objectives for a marine protected area may be beyond realistic definition. Indeed, it seems inevitable that optimization may need to be an iterative and adaptive process; verification of optimal design and management is unlikely ever to be a definitive goal. Nevertheless, the existence of such uncertainties and indeterminacies should not be used to argue against the closure of marine areas to all human activities as one component strategy to conserve biodiversity. On the contrary, these characteristics emphasize further the fundamental importance of the more precautionary management elements that come from a protected area approach.

Allison, Lubchenco and Carr (1998), while noting the limitations to conservation effectiveness conferred by marine reserves (principally in that they clearly cannot provide a physical barrier to the impacts of some changes occurring at broader spatial scales), nevertheless view them as an essential component of future marine management programmes. These authors advocate substantial increases in the number and size of such designated areas, while noting that such developments must go hand-in-hand with a diversity of other measures aimed at protecting habitat and biodiversity even beyond the boundaries of reserves. In short, they see marine reserves as "necessary, but not sufficient" to guarantee a high probability of effective marine conservation.

## 6. SEAMOUNT EXPLOITATION AND SUSTAINABILITY

The view expressed by Richer de Forges, Koslow and Poore (2000) that "the highly localized distribution of many seamount species has profound implications for their conservation" is now almost beyond disagreement. The question of what this means in terms of the management of human activities on, and over, seamounts remains the subject of intense debate. A central guiding principle in future decisions regarding their conservation should be that any permitted activities must be compatible with the overarching goal of sustainability.

One relevant question is "can seamounts ever be fished sustainably?". In answer, it is fair to say that there is little, if any, evidence that they have been to date, especially in relation to the exploitation of bethopelagic fish using bottom trawls. Even in pure fisheries management terms of stock assessments and fishery management plans, the picture is bleak. If one considers impacts at a broader ecosystem level, it is difficult to see how experience to date could fit with any reasonable definition of sustainability.

As an example, the six "principles for sustainable governance of the oceans" proposed by Costanza *et al.* (1998) provide valuable guidance for the development of future marine management regimes capable of addressing current patterns of overexploitation and loss of biodiversity. Of these principles, those of precaution and of responsibility to ensure that any use is sustainable have particular relevance to the protection of seamount ecosystems. We have already noted the enormous uncertainties associated with the structure and dynamics of seamount ecosystems and their response to human disturbance. At the same time, it is difficult to see how exploitation of seamount fisheries to date could ever be described as "sustainable", even in the strictly limited terms of basic fisheries management.

Costanza *et al.* (1998) also propose that all existing or proposed activities should be subject to "full cost allocation", including all internal and external costs and benefits. The fundamental difficulty here is that whereas it is relatively simple to assign a value to the economic benefits of exploitation (e.g. total export value of a given fishery), the costs in terms of ecological damage are almost impossible to quantify fully, let alone express in equivalent monetary terms. What does seem to be clear, however, is that the benefits of fisheries such as those targeting orange roughy in New Zealand and Australian waters are almost exclusively economic. Given the high costs inherent in catching such species, their consequent high value per tonne and the relatively limited contribution they make to the global availability of seafood and food security in general, it is difficult to see how seamount fisheries substantially contribute to social equity.

Comparison against other recognized definitions of sustainability lead to similar conclusions. For example, two of the four "first order principles" proposed by Cairns (1997) are:

> *"(3) the physical basis for productivity and diversity of nature must not be systematically diminished and (4) fair and efficient use of resources with respect to meeting human needs."*

Both could be seen to be violated by the practice of bottom trawling alone. Nor is it conceivable that other potentially damaging human activities, such as seabed mining, oil or gas extraction or waste disposal, could ever be conducted in the vicinity of seamounts in a manner consistent with these broad principles of sustainability.

## 7. CONCLUSIONS

The deep sea is a reservoir of biodiversity and as such must be recognized as a priority for the development of suitably protective measures, both in waters of coastal states and on the high seas. Seamounts are an important part of the deep-sea environment, given their propensity to support particularly rich and abundant faunal communities. Moreover, it is these structures that are already among the most exploited and threatened features of the deep sea. To date, destructive fishing practices, especially bottom trawling, are undoubtedly responsible for the greater part of adverse impacts, although many other ongoing or potential future human activities also pose substantial threats.

In this context, an immediate moratorium on the use of bottom trawls and other destructive fishing gear on seamounts would be an invaluable and entirely justified response. In the longer term, such an action must form part of a more concerted effort to greatly increase the number of seamounts around the globe conferred protection from the full spectrum of damaging human activities through designation as MPAs.

These two approaches, the universal application of fishing gear restrictions and the establishment and management of MPAs are by no means incompatible. Rather they could prove complementary, not least because an immediate decline in the rate of seamount exploitation would ensure a much greater availability of unaffected, or only partially affected, regions that could then form vital components of representative networks of well managed MPAs.

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