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Abstract

Around 0.04% of the world's marine area is presently designated as no-take zone (NTZ), in which all fishing is banned. The IUCN, backed by many marine fisheries and ecology scientists, has called for this to be increased to 20-30% by 2012 in order to conserve fish stocks and marine biodiversity. This ambitious target presents a number of collective action problems (CAPs) that must be addressed and overcome if fishers and other relevant actors are to collaborate towards its achievement. These are discussed, drawing on the common-pool resource (CPR) literature, with particular reference to those raised by divergent aims, predictability, different knowledges, role of advocacy, locality, level of decision-making and enforceability. As NTZs are ultimately about altering the behaviour of humans, it is argued that studies based on social sciences, on how NTZs can be designed, implemented and enforced on a collective basis, are essential.

Introduction

No-take zones (NTZs) can be defined as marine areas in which the extraction of living and non-living resources is permanently prohibited, except as necessary for monitoring or research to evaluate effectiveness [1]. As such they are the most restrictive type of marine protected area (MPA), this being a general term for a wide variety of designations which confer varying degrees and types of protection. NTZs are thus equivalent to Category I (strict nature reserve/wilderness area) under the IUCN's protected area management categories [2], though a wide variety of designation terms is used to describe them, e.g. marine reserves, highly protected marine areas, marine preservation zone, scientific zone. There has been a rapidly growing interest in recent years in the potential of NTZs as a partial solution to the challenges of declines in both fish stocks and marine biodiversity. The increasing number of publications on various aspects of NTZs [3, 4] reflects this interest. The foci of these publications vary, but the majority draw on marine fisheries and/or ecological sciences. However, very few papers have analysed the social challenges posed by NTZs. This paper makes a contribution to filling this gap by analysing the collective action problems (CAPs) posed by NTZs, particularly those in territorial seas out to 12 nm, drawing on the common-pool resource (CPR) literature. It is important to note that this paper is strictly focused on CAPs posed by NTZs, and is not a wider analysis of fisheries management drawing on CPR theories, on which there is already a wide literature[1].

It is estimated that less than 0.5% of the area of the world's oceans is designated as MPA [8, 9]. Yet a smaller percentage is fully protected as NTZ, estimated in 2000 at around only 0.01% [10]. Considering this minuscule proportion, the IUCN's recommendation that 20-30% of each marine habitat should be designated as NTZ by 2012[2] is clearly very ambitious, though, as Suzuki [12] notes, such recommendations are easily ignored. The 2002 World Summit on Sustainable Development was less ambitious in that whilst it called for the restoration of depleted fish stock and a representative network of MPAs, it did not include an explicit target for permanent NTZs[3]. However, there have been many calls for a much greater proportion of the world's seas to be designated as NTZs, particularly in the late 1990's and early 2000's, which support the IUCN's target[2]. In 1998, 1605 marine scientists signed a call for governments to protect 20% of the world's seas from threats by 2020 [14, 15]. Similarly, in 2001, 161 marine scientists signed a scientific consensus statement calling for a network of NTZs to conserve fisheries and marine biodiversity [16], as the culmination of a three-year research project [17].

At around the same time the USA's National Research Council published a detailed analysis and guide on MPAs which was largely focused on NTZs [1], whilst WWF commissioned a comprehensive guide to NTZs [8]. There were also many papers stressing the impacts of fishing on ecosystems [18-23] and arguing for NTZs [10, 24-28]; highlighting the impacts of fishing on species [29], e.g. sharks [30] and other chondrichthyans [31], sea turtles [32], cetaceans [33, 34], and shellfish-eating birds [35]; stressing the potential benefits of NTZs based on models [36-43]; and reporting the observed effectiveness of NTZs in providing for the recovery of fish populations within [44-46] and beyond [47, 48] their boundaries.

In the face of this large number of recent publications making the case for NTZs, it could easily be concluded that there is a consensus on their need and that the prospects for achieving the IUCN's 20-30% NTZ target[2] are therefore relatively good. However, there are many who challenge the case for NTZs on various grounds, e.g. most fish stocks are too mobile for such site-specific approaches [49]; decreasing overall effort is far more effective for conserving fish stocks and avoiding ecosystem regime shifts [50], both accordingly arguing that modern fisheries management approaches (MFMAs), such as quotas and technical measures, may often be more

[1] See, for example, chapters 1, 6, 8 & 10 [5] of Ostrom et al. [6] and chapters 2, 3, 5 & 6 of Dolšak and Ostrom [7].

[2] Recommendation 5.22 calls "on the international community as a whole to…. 1) Establish by 2012 a global system of effectively managed, representative networks of marine and coastal protected areas… a) these networks should be extensive and include strictly protected areas that amount to at least 20-30% of each habitat" [11]. The rough area estimate of 0.01% in 2000 [10] does not include, *inter alia*, the 2004 addition of around 99000 km^2 NTZ in the Great Barrier Reef Marine Park. This alone raised the NTZ area figure to around 0.04%, compared to which the IUCN target represents a 500-750 times increase in eight years, at the time of writing.

[3] 30(a) Maintain or restore stocks to levels that can produce the maximum sustainable yield with the aim of achieving these goals for depleted stocks on an urgent basis; 31(c)… the establishment of marine protected areas… including representative networks by 2012 and time/area closures for the protection of nursery grounds and periods [13].

effective than NTZs. Willis at al. [3] declare themselves as proponents of NTZs, but review papers that question the validity of many of the theoretical speculations based on models that have been made for their potential benefits, and question the scientific rigour of much of the empirical evidence for the recovery of fish populations within them.

Many of the arguments for and against NTZs are represented in a forum of seven viewpoint papers [51] by marine biologists, fishery biologists and fishers. An analysis of these and other papers indicates that the consensus on the need for NTZs may actually be confined to quite a narrow constituency. Table 1 summarises the main positions for and against NTZs. Shipp's critical perspective on NTZs [49] prompted a rebuttal [52] that countered many of his arguments, and debates on the merits of NTZs will no doubt continue. Whilst Table 1 reveals that the number of author's arguing for NTZs is greater than the number arguing against, the pattern, in practice, is for fishers to tend to object to and resist NTZ proposals on a variety of grounds, e.g. (a) the potential benefits of such designations are largely unproven [4, 51], a position which Polunin [53] argues is scientifically justified, whilst the losses to excluded fishers are immediate and obvious; (b) the presumption that fishing should be allowed everywhere all the time unless negative impacts on stock sustainability can be proven [54]; and (c) the tendency for people to almost reflexively oppose restrictions to what they can do on the global commons [28]. Such objections and resistance will no doubt continue to be a considerable hindrance to the achievement of the IUCN's target[2].

Against this background, this paper will analyse some of the challenges to gaining the agreement and cooperation of fishers with NTZs. These are considered as collective action problems (CAPs), i.e. the general challenges that must be addressed and overcome if actors are to collectively govern CPRs. The CPR literature argues that such CAPs must be overcome, through the re-design of institutional arrangements, if more collaborative management (hereafter co-management) initiatives are to be effective [55-57]. There is growing interest in the potential of co-management as a means of achieving sustainable marine fisheries management [58-66] on the basis that such governance approaches, whereby the state and the fishing industry work on a partnership rather than adversarial basis, are essential given the evident failure of top-down government approaches [5]. However, if such governance approaches are to be pursued, including even partial fulfilment of the IUCN target[2] through the designation of more NTZs, it will be necessary to overcome the CAPs posed by NTZs. Hilborn et al. [67] argue, however, that NTZs are merely 'band-aids' that address the symptoms of overfishing , and that rather than specifically pursuing NTZs as part of an ecosystem approach, the emphasis should be on developing wider solutions through more bottom-up, community rights-based approaches to fisheries management. Against this complex background of perspectives, this paper will focus on the CAPs posed by NTZs, in particular those related to seven issues: divergent aims; predictability; different knowledges; role of advocacy; locality; level of decision-making; and enforceability.

Divergent aims

NTZs are often discussed as a win-win strategy [68, 69], in that they will confer benefits for both marine biodiversity[4] and fisheries conservation [17, 25, 48]. However, Ballantine [70] argues that the primary aim of NTZs is to conserve or restore marine biodiversity, and that whilst it is likely benefits will also be provided for fisheries, such benefits should be regarded as bonuses. Similarly, Halpern et al. [38] argue that NTZs "need not, and perhaps should not, be designed with fisheries management as a primary goal". These views are supported by the NFCC Consensus Statement [71], which argues that whilst NTZs have a clear and generally accepted application for meeting marine biodiversity conservation objectives, their potential role in fisheries management is controversial as evidence for their wider benefits is lacking.

There are clearly benefits to promoting NTZs as win-win strategies. Wider larval spillover [28, 36] and adult export [47, 48] benefits thus become a means of reducing the potential for objections from fishers who will otherwise see NTZs purely as a marine biodiversity conservation initiative from which they stand to lose by their exclusion from fishing grounds. Given enough evidence of the wider fisheries benefits of NTZs, many fishers could become proponents.

However, it could be questioned whether it is valid and necessary to 'sell' the resource management benefits of NTZs, i.e. terrestrial conservationists do not have to convince hunters that protected areas will produce a surplus of wildlife that spills over and supports surrounding hunting communities [51], so why should marine conservationists have to 'sell' NTZs on the basis of their wider benefits for fisheries exploitation? Why should we not think of NTZs in the same way as we think about terrestrial protected areas - simply as secure havens for biodiversity [51]. It could be argued that the scale and connectivity of the marine environment, coupled with the presumption of multiple-use of marine areas and the view that society's relation to the 'alien' sea is largely defined in terms of the resources it provides [4], undermines these comparative question. It could be counter-argued that another objective of NTZs is to challenge and transform such presumptions and views.

This question and arguments aside, it is debatable whether NTZs can be pursued as a single tool to achieve both aims. NTZs aimed primarily at achieving marine biodiversity conservation objectives will have different design and implementation criteria to those aimed primarily at achieving fisheries management objectives [1, 72]. Roberts [73], for instance, discusses conflicts between the design of NTZs for fisheries and marine biodiversity conservation functions, related to whether coral reef NTZs should be designed to facilitate or minimise spillover. Simberloff [74] notes that whilst the two aims are not necessarily mutually exclusive, the criteria for evaluating success for each would be very different.

There is also evidence that NTZs may actually undermine fisheries conservation objectives as a result, for example, of increases in fish stock predators [75, 76] and of lower growth rates due to overcrowding [77]. Table 1 reveals that many consider MFMAs to be more effective for fisheries conservation than NTZs. Such MFMAs could be incorporated within a sustainable multiple-use MPA zonation scheme, which could incorporate core NTZs aimed at protecting areas primarily for marine biodiversity conservation objectives. Such combined approaches will reconcile the rift that, it has been argued, has been constructed between the two types of designation [78] and overcome the related single large or several small (SLOSS) reserves debate [4]. However, the debate on the proportion of multiple-use MPAs and of the total marine area that NTZs represents will continue [4]. In this respect, Agardy et al. [78] argue against numerical targets for NTZs on the grounds that they become ill-substantiated mantras that could undermine support for multiple-use MPAs. They would clearly not support the IUCN's NTZ target[2].

This target reflects the assumption that NTZs are the only legitimate MPA, an assumption that Agardy et al. are critical of. This assumption is arguably itself a reflection of different underlying ethical perspectives, NTZ proponents being more influenced by preservationist and ecocentric perspectives, and multiple-use MPA proponents being more influenced by the utilitarian resource conservation perspective[5]. The potential for the

[4] The general term 'marine biodiversity' is used to describe both structure-oriented (focus on conserving representative habitats and threatened species) and process-oriented (focus on conserving ecosystem processes) perspectives [4], in keeping with the definition of biodiversity by the Convention on Biological Diversity [Article 2, www.biodiv.org/convention/articles.asp]

[5] See Callicot [79] for an outline of these ethical perspectives in the context of fisheries management.

convergence of these different perspectives may be limited given Miller and Kirk's [80] argument that when a problem is based on competing ethics, "negotiated settlement is foreclosed because consensus is philosophically intolerable". The divergence between proponents of NTZs for fish stock conservation, with the emphasis on larger multiple-use MPAs which might include NTZs but without area targets, and of NTZs for marine biodiversity conservation objectives, with the emphasis on achieving NTZ area targets, is therefore very significant and might be considered as a basic conflict [4]. This divergence is reflected in the difference between the WSSD target for MPAs[3], implicitly incorporating NTZs but not specifying an area target, and the IUCN 20-30% area target[2], the former being driven by wider resource conservation concerns and the latter by specific nature conservation concerns.

A key implication of this divergence is that pursuing NTZs on a win-win basis could be counter-productive, as the aims of marine biodiversity and fish stock conservation may not be compatible in some cases. For instance, Fanshawe at al. [75] argue that where restored top carnivores limit the sustainability of a commodity harvest, two categories of NTZs may be needed, one focusing on ecosystem restoration and one on fishery development, in order to resolve the conflict, an approach which is consistent with Ballantine's argument [70] discussed above. Such a dual approach would not avoid the CAPs associated with closing areas to fishing for marine biodiversity conservation purposes, but it would avoid the CAPs that could emerge if NTZs are widely promoted on a win-win basis when the divergence between these aims may, in some cases, undermine such a combined approach.

Predictability

Marine ecosystems tend to be relatively complex and display high degrees of variability, and it can be extremely difficult to predict the impacts of human interventions such as NTZs. Our relatively poor understanding of the complex dynamics of marine ecosystems [4] compounds this challenge. Researchers investigating the validity of CPR governance approaches have identified a number of critical enabling conditions for the sustainability of CPRs [81]. Whilst they are arguably not all universally critical, their non-fulfilment in a given CPR system does represent a significant challenge for the governance of the CPRs in question, in effect posing a number of related CAPs. A key resource system condition is that the flow of resource units should be reasonably predictable, Baland and Platteau [82] identifying lack of resource knowledge as one of the main factors that drives users to over-exploit CPRs. Our inability to predict the behaviour of natural resources is generally discussed in terms of scientific uncertainty.

There is considerable debate as to how natural resource conservation initiatives should proceed in the face of such uncertainty. Ludwig et al. [83] propose that full scientific consensus concerning fisheries and marine ecosystems shall never be attained, as controlled and replicated experiments are impossible to perform in such large scale systems. With specific regards to NTZs, as is discussed above, many of the predictions of their effects based on modelling exercises have been criticised on the grounds that they are based on assumptions that ignore the complexity of marine ecosystems [3]. Empirical evaluations of actual NTZ effects are also fraught with difficulties as good controls are very difficult to find due to the connectivity of marine ecosystems [38, 47]. Furthermore, the natural variability of marine ecosystems means that it is difficult to distinguish between NTZ effects and such variability [38, 84, 85]

Such difficulties support, in specific relation to NTZs, Ludwig et al.'s [83] argument concerning the unattainability of scientific consensus. Wilson [5] builds on these arguments in discussing how the quest for such certainty and consensus in complex marine ecosystems is inappropriate, as it assumes that we are dealing with a simple Newtonian system in which species dynamics and cause-effect relationships can be determined. It could therefore be argued that attempts to predict and monitor the effects of NTZs are falling into the same 'reductive trap' as fisheries models, in that they are based on the same Newtonian rationale. Wilson [5] argues that the inappropriateness of this rationale is one of the key factors behind the failure of MFMAs. The application of this rationale to NTZs is thus arguably perpetuating the reductive approach that led to the fish stock and marine ecosystem declines, which are a key basis for calls for NTZs.

So how can NTZs avoid this 'reductive trap' and move forward? Ludwig et al. [83] argue that scientific uncertainty is not necessarily an obstacle to conservation initiatives, in that actions should be taken on an iterative, adaptive basis which recognises scientific uncertainty, rather than delaying actions in the quest for scientific certainty. Similarly, and in specific relation to NTZs, the NFCC Consensus Statement [71] argues that

there is currently sufficient knowledge to proceed with NTZs to achieve fisheries management goals, provided an adaptive approach is adopted. Wilson [5] again builds on such arguments in his proposals for developing polycentric hierarchical fisheries management institutions that are congruous with the complex spatial dynamics of marine ecosystems. These would provide for uncertainty to be reduced by learning, through exchanged observations and experiences, how marine ecosystems tend to adapt to exploitation and related management interventions, such as NTZs.

Such arguments indicate that a lack of predictability need not be a barrier to CPR governance initiatives, provided the institutions are adapted to uncertainty [5]. One means of adapting to uncertainty is to take a more precautionary approach, which is a management philosophy that favours constraining an activity when there is high scientific uncertainty regarding its environmental effects [1]. Accordingly, there have been calls for NTZs to be established on a precautionary basis [25, 86], in keeping with calls for reversing the burden of proof in fisheries management [87]. However, in the context of the current reductive fisheries management approach, the difficulties, if not impossibility, of predicting and proving the benefits of NTZs aimed at fish stock conservation are highly likely to lead to CAPs for such precautionary NTZs, which may often be insurmountable. Fishers and their regulators are much more likely to vigorously object to NTZ proposals where uncertainty is high and predictability is lacking, and NTZs that are designated in the face of such objections are likely to be more difficult to enforce.

It is important to note that the issue of predictability largely applies to the potential fisheries management benefits of NTZs. The marine biodiversity benefits are far more predictable. The major biodiversity impacts of fishing on seabed communities are well documented, mainly through the reduction of structural complexity [88, 89]. However, these studies also reveal that habitat complexity and biodiversity can often fully recover, though over varying periods of time. In a similar manner, the ecosystem and species impacts of fishing [10, 18-35] will clearly be prevented in a given area if fishing ceases through NTZ designation, allowing the marine ecosystem and associated species to recover, provided the ecosystem has not shifted to an alternative stable state (ASS) and the species are not too severely extirpated. There is therefore a clear divergence of predictability between the fisheries and biodiversity benefits of NTZs, unpredictability arguably only applying to the former. If the objectives of NTZs are primarily focused on the biodiversity benefits, unpredictability is far less significant an issue, as are the related CAPs, though major CAPs would be posed through the resistance of fishers to NTZs focused on such benefits.

Different knowledges

Many argue that the integration of local fishers' knowledge with 'expert' knowledge is essential for effective fisheries management [90-92]. Local knowledge amongst resource exploiters should thus be treated in the same way as scientific knowledge, rather than being discounted on the basis of a lack of training or social position [93]. Many also argue that science is no longer independent of societal values, and that experts and lay people should share knowledge and deliberate on the validity of differing judgements, including considerations of underlying value perspectives [94, 95].

These views on the role of lay and expert knowledges are not reflected in MFMAs, in which experts set harvest limits based on reductive models, regulators interpret them and allocate quotas, and reluctant fishers are expected to comply. The scepticism of fishers about the reductive basis for setting limits is a factor that influences them to defy quotas and other restrictions, often successfully. On this basis Wilson [5] argues that the reliance of MFMAs on 'expert' knowledge is a key factor in their failure, as it undermines the potential for mutual restraint amongst fishers and ignores their detailed local knowledge. He proposes an alternative approach whereby polycentric hierarchical institutions are designed that do not make reductive assumptions about fisheries dynamics, but do emphasise the role of collective learning amongst scientists and fishers. Such multi-scale collective learning networks could provide for the detailed local knowledge and experiences of fishers to be combined with the larger scale knowledge of scientists, in a manner that enhances the capacity to adapt to complexity and uncertainty.

With more specific regards to NTZs, there is a divergence between those who believe they should be designed and managed primarily on the basis of expert scientific information, and those who believe they should be designed and managed on a more collective basis, also drawing on local community knowledge [4]. The expert basis position is clearly more consistent with MFMAs and places a major emphasis on the development of

theories and models, such as those currently being developed [17, 36-43], whilst the collective basis position is more consistent with Wilson's [5] collective learning networks approach. In support of the latter, it has been argued that the exchange amongst fishers of assessments of the fisheries and ecosystem benefits of NTZs will have more influence than quantitatively rigorous scientific assessments [47, 96].

Whilst there are different views on the relative validity of expert and local knowledges in the design and management of NTZs, it is clear that CAPs will be raised if this does not sufficiently provide for the inclusion of fishers knowledge based on their local, long-term experience. Approaches that promote collective learning amongst fishers and experts are likely to be effective in minimising such CAPs, as well as those discussed above related to unpredictability. As such, it is argued that 'consensus on the validity of different knowledges' is an important condition for CPR governance, particularly NTZs, though it is not included in Agrawal's [81] analysis of such conditions.

Role of advocacy

The forum on marine reserves [51] includes mutual criticisms that those arguing for them were funded by a marine conservation foundation, and those arguing against them were funded by a marine fishers' foundation. These criticisms are consistent with the argument that partnerships between conservation NGOs/donors and scientists may lead to biased or partial representations of the ecological and social impacts of MPAs [97]. This is typical of concerns that the difference between science and advocacy in this field is becoming increasingly blurred [53]. Many of these criticisms are aimed at those advocating NTZs, mainly because there are relatively few publications that argue against them. Willis et al. [3] argue that the *raison d'être* for many review and theory papers concerning NTZs is advocacy for such designations, rather than real attempts to contribute to the science of the field.

There have been several recent calls for scientists to become more involved in environmental policy debates in order to provide for their expert views and concerns to inform such debates and decisions [12, 98, 99]. Such increased involvement is recognised as being particularly important where decision stakes and uncertainty are high and there are many value perspectives [95], as is discussed above in the preceding section on knowledges. However, these calls are for involvement through the presentation of knowledge based on scientifically informed concerns, not advocacy through proposing or recommending policies, or supporting causes. Myers [99] urges scientists to avoid becoming advocates, by ensuring that they remain rigorous rather than descending into rhetoric, and by making clear where there are uncertainties over their knowledge, though in relation to the latter he also stresses that uncertainty surrounding concerns should not become a basis for not communicating them. Mackey's [100] response to Myers [99] agrees that scientists have a moral obligation to inform society if they believe that the earth's ecological life support systems are being damaged. He stresses that rather than adopting an advocacy role by promoting specified outcomes, scientists should adopt a mediation role, by providing information about the potential outcomes of various policy options to achieve concrete goals. He also argues, in keeping with the discussions above on the precautionary role of NTZs, that the principles of the Earth Charter could support the role of scientists as 'honest brokers'.

Against this background, the extent and impacts of advocacy in NTZ debates is itself debatable, as the distinction between mediation and advocacy is, indeed, a blurred one. It could be argued that scientists highlighting the impacts of fishing on marine ecosystems, as discussed in the introduction to this paper, were highlighting a valid concern, entirely in keeping with the above principles, with the goal of reducing such impacts. However, those promoting NTZs as the key means of achieving this goal could be considered to be focusing on a single policy option, and thus straying into the realms of advocacy, whilst those who specify a specific NTZ target area are even further into such realms[6]. It is important to distinguish between the IUCN's 20-30% NTZ target[2], which is valid given the campaigning role of this NGO, and the call for a 20% target from scientists [14, 15]. In relation to the latter, Agardy et al. [78] argue that advocating such empirically untested and simplistic 'rules of thumb' creates dangerous targets that could threaten progress in marine conservation by raising inflated expectations, polarising arguments and provoking a policy backlash. Hilborn et al. [101]

[6] It is interesting to note in this respect that the NFCC Consensus Statement [71] explicitly recognises that its presentation panel was "made up of scientists and policy experts that are currently engaged in research or advocacy in the field of marine reserves"

similarly argue that unqualified advocacy for NTZs ignores the potential negative impacts to fish stocks and fishing communities, and that it is misleading to promote them on the basis that they are always likely to result in improved yields. A contributor to the marine reserve forum [51] accuses advocates both for and against NTZs of polarising arguments through oversimplification.

So what are the implications of advocacy, accepting that the distinction between it and mediation is a blurred one, in terms of raising CAPs for NTZ? Fishers are likely to object more strongly if they believe that NTZs are being promoted by scientists as a main policy option on an apparently objective basis, on the grounds that they can achieve both fisheries and marine biodiversity goals, when they suspect that the implicit motives are more preservationist and related to the latter goal [4], and this is likely to raise considerable CAPs. The polarisation of the debate by those from fisheries and marine biodiversity perspectives adopting the position of advocates is also likely to raise CAPs. Such CAPs are likely to have a particular impact should fishers and scientists subsequently be expected to collectively learn through NTZ networks in keeping with Wilson's [5] vision.

Locality

Marine habitats and species tend to have relatively wide distributions, with many species and their propagules actively or passively moving over hundreds or even thousands of km's in their life cycles. Areas that are spatially separated are therefore more likely to be functionally connected in marine ecosystems than in terrestrial ecosystems [4]. These inter-related attributes of scale and connectivity pose particular challenges as they mean that many fish stocks tend not to be localised and are therefore not consistent with four of the resource system characteristics that are critical enabling conditions for sustainable CPR governance [81], i.e. small size, well-defined boundaries, low levels of mobility and possibilities of storage of resource benefits. This lack of locality poses a number of related CAPs.

Where NTZs are designed to protect highly mobile species, particularly through the protection of areas that are critical during certain stages of their life history [102], the fishery benefits will be spread over a wide area through the migration of adults and export of propagules. Fishers in the locality of the NTZ affected by the closure will therefore only receive a small proportion of the NTZ benefits, as they will have to share them with other fishers over a wide geographic area. There will, however, be local benefits for overfished stocks with low mobility or territorial adults, provided mobility is high enough to provide for export from the NTZ [49].

Another consequence of the scale and connectivity of marine ecosystems is the potential for impacts derived from activities outside NTZs to undermine local conservation efforts [103], e.g. through the distant harvesting of migratory populations, climate change [104], trophic cascades [105] and invasive species [74]. Such impacts, or even their potential, may undermine the motivation of local fishers to act, thus posing a significant CAP. This supports Berkes' [106] arguments that CPRs need to be managed at a variety of different scales, in which horizontal (across geographical space) linkages are important. Wilson [5] similarly argues for fisheries to be managed through a hierarchy of institutional structures, higher levels addressing wider-scale issues. Thus local NTZs would be integrated with wider scale fishery and environmental management initiatives in order to address externally derived impacts. It is, however, unlikely that all such impacts will be able to be ameliorated through such approaches, so NTZs are always likely to have to address the CAPs posed by scale and connectivity.

There is also considerable potential for non-local fishers to come into an NTZ, or the area around it that is locally benefited by export/spillover, and freeride by harvesting stocks that have been increased through local restraint. Such incoming transgressors will clearly undermine the motivation of locals to employ such restraint. Indeed, exploitation from non-locals is widely recognised as representing one of the main threats to the conservation of natural resources, though it is also recognised that alliances between government agencies and local stakeholders can be an important means of fending off such threats [107]. Such alliances present a significant positive opportunity for NTZs, whereby any costs incurred by local fishers through employing restraint can be compensated for by introducing a degree of local protectionism to exclude incoming freeriders. This is consistent with Rydin and Pennington's [108] argument that spatially delimited, localised environmental governance is particularly effective in enabling stakeholders to overcome CAPs, and that there may need to be rules which prevent the participation of non-locals who have a higher potential to free-ride. It is also a good example of how synergies can be created between conservation objectives and those of local stakeholders [109], in that government agencies might regard the restraint of local fishers as a means of achieving fisheries and

marine biodiversity conservation ends, whilst stakeholders might regard local protectionism as an end to be achieved through the means of such conservation.

Level of decision-making

One of the CPR governance conditions is that decisions over access and management rules should be taken locally, whilst another is that the central government should not undermine local authority [81], both implying that CPR governance is most effective where management decisions are largely taken by locals. There is, however, a divergence between those who argue that MPAs should be managed on a top-down basis, whereby government agencies have a dominant decision-making role, and those that argue that they should be managed on a bottom-up basis, whereby local MPA users have a dominant decision-making role [4]. There is a similar divergence in the specific context of NTZs, Erwin [110] arguing that decisions should be taken at as high a level as possible in order to avoid fishers' vested interests undermining marine biodiversity conservation objectives, whilst Hilborn et al. [101] argue that the top-down imposition of NTZs is as unlikely to work as the attempted imposition of MFMAs has proved to be, in keeping with Wilson's [5] views on such attempts discussed above. These contrasting arguments resonate with arguments that too bottom-up an approach raises the risks of parochialism (domination by local resource exploitation interests) and too top-down an approach raises the risks of imposition (apathy, objections, non-cooperation and defiance) [111]. In this respect, Berkes [106] notes that "the balance of evidence from the commons literature of the past few decades is that neither purely local-level management nor purely higher-level management works well by itself".

It is important to recognise that these divergent perspectives are, to a degree, an expression of the divergent aims discussed above, whereby those focused on marine biodiversity aims tend to favour more top-down approaches [110] whilst those focused on fisheries conservation objectives tend to prefer more bottom-up approaches [67]. Furthermore, many are now arguing, both in the context of MPAs [4, 112] and in fisheries management [58-66], for a more balanced approach whereby top-down and bottom-up approaches are combined, with government agencies and fishers working on a partnership basis [111], in keeping with the concept of collaborative management [107]. However, the question remains as to what balance of power will be appropriate in such partnerships in order to balance the achievement of wider-scale, strategic goals with the fulfilment of more local priorities [111]. This question can be related to Wilson's [5] vision for polycentric hierarchical management institutions, discussed above, in that it could be argued that the higher level institutions with more wider-scale, strategic priorities will need to have a degree of power over lower level institutions, raising the risks of imposition and highlighting the importance of carefully managing top-down management interventions [111].

The key question, however, remains: what is the appropriate balance of power amongst different institutional layers, and more specifically, what is the role of local fishers in decisions concerning NTZs which affect them? The balance will, of course, very much depend on the context, particularly the aims of the NTZ in question, the geographic scale of the fishery and ecosystem in question, and the nature of the related CAPs which need to be overcome. Rydin and Pennington [108] argue that in cases where CAPs are severe, particularly where priorities amongst different locations must be balanced, it is often appropriate to adopt a more top-down approach, as this is the only feasible way of addressing such CAPs. This is consistent with Dryzek's [113] argument that as the geographic scale and scope of resource exploitation interdependencies increases, the need for some central authority to coordinate negotiations and enforce agreements also increases, as discussed by Milon [114] in the specific context of NTZs against the background of the scale, connectivity and complexity of fisheries. However, Milon also recognises that the risks of imposition increase as decision-making becomes more centralised.

This circular argument, then, brings us back to the above key question and highlights a dilemma, i.e. that top-down decisions raise the risks of imposition whilst bottom-up decisions raise the risks of parochialism [111]. Wilson's [5] proposals for collective learning networks amongst fishers and scientists may have some potential to bridge the divide between top-down and bottom-up decision-making, and thus reconcile this dilemma. It is clear, however, that the level at which NTZ decisions are taken will raise significant CAPs for NTZs, and that these will need to be carefully addressed by initiatives to achieve the IUCN target[2].

Enforceability

The challenge of excludability is recognised as a critical issue for the management of CPRs in general [55]. The exclusion of certain users and types of uses at sea, which is vital if resource exploitation measures are to be enforced, is widely recognised as being a particular challenge due to the logistical requirements, expense and risks of mounting surveillance patrols, given the wide-scale of the marine areas being policed. Such difficulties are widely recognised, in particular, as being a significant factor behind the failure of MFMAs in many cases. However, an important argument for NTZs is that they are simpler and easier to enforce than MFMAs [36, 71, 96], in that it is not a matter of boarding a fishing vessel to check that it is licensed, within quota, adhering to minimum size limits, using the right gear, etc, but simply a matter of ascertaining and proving whether the vessel is fishing. Such designations may thus better fulfil the two CPR governance conditions that rules are simple and easy to understand, and easy to enforce [81]. NTZs also have less potential for fishers to be able to overcome restrictions through the evolution of fishing practices [71]. However, enforcing NTZs remains a major challenge, Davis et al. [115] reporting that illegal fishing in NTZs on the Great Barrier Reef Marine Park (GBRMP) occurred at significant levels, particularly for more remote NTZs. Whilst they found that illegal fishing decreased as surveillance effort increased, they highlight the challenges posed if sufficient surveillance is to be ensured now that the NTZ areas has increased from 4.6% to 33% of the GBRMP area. Given that the IUCN 20-30% NTZ target[2] represents a marine area of around 72-108 million km^2, it is clear that the surveillance and enforcement of NTZs over such a vast areas will be a major challenge.

The degree of enforcement required to ensure the compliance of fishers with NTZs is strongly affected by the six issues discussed above. It can be reduced if fishers are involved in NTZ design and management [1, 111, 116] through co-management approaches [58-66]; therefore the *level of decision-making* is critical in this respect. Similarly, the promotion of a sense of local ownership of the resources can ease enforcement [1, 8]; therefore the above discussions concerning *locality* are also critical in this respect. In particular, it is important that there are statutory provisions that require the compliance of potential freeriders, be they non-locals or locals, and that they are effectively enforced. If a freeriding minority is seen to benefit by harvesting fish stocks in an NTZ that have been increased through the restraint of the majority, resentment will be fostered and the potential for cooperation with the NTZ will be critically undermined [1, 8, 117]. The discussions concerning *different knowledges* are critical in that reliance on 'expert' knowledge undermines the potential for mutual restraint amongst fishers [5], therefore providing for fisher's knowledge to be employed in NTZ decisions and increasing their respect for the scientific basis of these decisions can promote their cooperation.

Divergent objectives can raise enforcement challenges where there is a lack of support for NTZs focused primarily on biodiversity conservation objectives, which might undermine the potential for cooperation, particularly if the *level of decision-making* about such designations is high, as previously discussed. Ballantine [118] reports that fishers who were initially divided about a proposed NTZ in New Zealand, came to appreciate the coincidental fisheries benefits that it provided, and most became active enforcers, through peer surveillance and pressure. In general, however, it is likely that biodiversity conservation-focused NTZs will face particular enforcement challenges, at least in the initial stages before any wider fish stock benefits are realised [8]. *Lack of predictability* is an important related issue, as it creates uncertainty and, potentially, scepticism amongst fishers concerning predictions of wider fish stock benefits, and may undermine their potential to cooperate. The *role of advocates* may also undermine such potential in cases where fishers believe that scientific advice in support of NTZs has been provided on a less than impartial basis.

The compensation of fishers excluded from NTZs [119] and of the other affected businesses [120] can also ease enforcement by minimising the development of resentment where individuals have to bear much of the costs to achieve wider benefits, though the question of compensation is rarely addressed in the literature [119]. Such compensation typically takes the form of financial remuneration, i.e. to excluded fishers for income foregone, perhaps in the form of payments to help them adjust by changing or moving their operations [120]. A problem with financial compensation is that most fisheries have common access in that they are not the subject of *localised* restricted entry schemes, therefore it is very difficult to identify all the fishers who should be compensated, and those local or incoming fishers that have not been compensated will have no such incentive [121]. Compensation may also involve projects to enhance fish stocks in nearby areas [119] e.g. through seeding to enhance nearby shellfish stocks [122]. A problem with nearby fish stock enhancement is that of *predictability*, in that it is very difficult to determine the potential benefits to fishers of seeding.

'Interpretive enforcement' through education is widely recognised as a means of gaining support for MPAs in order to promote compliance [117]. Making fishers more aware of the objectives of NTZs and of the potential wider benefits should encourage their restraint. Such enforcement may be regarded as sufficient in itself to promote stakeholder understanding and compliance based on the 'information deficit' model [123], but, in keeping with the many challenges to this model, it has been argued that education and awareness raising is a pre-requisite for more significant participation in MPA decision-making processes, not a substitute [124]. Primary reliance on interpretive enforcement, at the cost of neglecting the other issues discussed in this paper, may actually provoke resentment amongst fishers on the grounds that they feel patronised, thus raising significant CAPs. The use of education and awareness-raising to compliment other initiatives to address such issues and the related CAPs is, however, clearly an important means of supporting enforcement.

It is also recognised that cooperation amongst different government agencies can be very important [116, 117], e.g. in providing for customs and police sea and air patrols to adopt NTZ surveillance and enforcement roles. Satellite surveillance technology may also have an important role, particularly for NTZs, which are further offshore, by employing vessel-monitoring systems to check whether fishing vessels are operating within NTZs [1, 96, 116]. However, this requires each monitored vessel to be equipped with a satellite transponder, at either the fishers' or government agency's expense, which may be an issue in relation to the CPR governance condition of low cost exclusion technology [81], though the value of many fisheries may warrant this expense. Lower cost alternatives for more inshore fisheries exploited by smaller commercial and artisanal vessels include hydrophone [8] and radar surveillance. It is also important to consider the prediction that the impacts of non-compliance will be greater for smaller NTZs, based on the assumption that fishers that violate NTZs tend to concentrate their activities near the boundary, where they are more quickly able to leave the NTZ and thus escape detection. This is clearly a factor that should be taken into account in network design, larger NTZs being better buffered against non-compliance than a network of small NTZs [125]. Finally, given that it is estimated that 12% of the world's fish catches are taken by recreational fishers [126] and that such fishing can have significant ecological impacts [127, 128] , it is imperative that NTZs are also enforced on this sector. One consequence of failure to do so is that commercial fishers may feel victimised.

Non-compliance resulting from poor enforcement critically undermines the achievement of NTZ objectives [8, 125], be these fish stock or marine biodiversity conservation-focused. It is therefore important that a progression of enforcement approaches is employed, as discussed above, including interpretation and providing for the inclusion of fishers and their knowledge in decision-making, as a means, *inter alia*, of promoting cooperation and peer enforcement, through to the employment of stringent statutory enforcement measures to punish the freeriding minority. The infringement of NTZs by even a very small minority of fishers is likely to both undermine conservation objectives and the potential for mutual restraint amongst otherwise cooperative fishers, but over-zealous use of stringent statutory enforcement measures may also raise the risks of imposition. A careful balance therefore needs to be struck in the use of such measures to avoid raising CAPs through their under or over-use, in keeping with the above discussions on the *level of decision-making*. Whilst the enforcement of NTZs is an issue that has received relatively little emphasis in NTZ studies [117, 125], it is argued that it is an issue that represents the critical operational aspect of all of the issues discussed above. It is therefore important that the implications for enforcement are considered at the earliest stages in NTZ initiatives in order that the issues discussed in this paper can be addressed in a manner that optimises the potential for effective enforcement, and thereby the achievement of NTZ objectives.

Conclusion

Initiatives to move towards the achievement of the IUCN's target[2] for NTZs will clearly raise many issues and related CAPs, particularly the seven discussed above. Experiences from proposed NTZs in California [129-131] reveal that many of these issues and related CAPs have, indeed, already emerged. Whilst studies based on fisheries and/or ecological sciences are clearly important in supporting the pursuance of the IUCN's target[2], it is argued that studies based on social sciences are equally as important [97], given that NTZs are ultimately about altering the behaviour of humans, particularly fishers. Such studies, particularly evaluations that analyse issues and initiatives emerging from actual NTZ experiences, will provide an important means of assessing and addressing the CAPs raised by NTZs, such as those discussed above. It is hoped that this paper will make a contribution to bridging the gap, on an interdisciplinary basis, between technical studies on why and how we should pursue NTZs, and social studies on how NTZs can actually be designed, implemented and enforced on a collective basis.

References

[1] National Research Council. Marine protected areas: tools for sustaining ocean ecosystems. Washington, DC: National Academy Press, 2001.

[2] IUCN Guidelines for protected area management categories. CNPPA with the assistance of the WCMC. Gland, Switzerland/Cambridge, UK: IUCN, 1994.

[3] Willis TJ, Miller RB, Babcock RC and Tolimieri N. Burdens of evidence and the benefits of marine reserves: putting Descartes before des horse? Environmental Conservation 2003;30(2):97-103.

[4] Jones PJS. Marine protected area strategies: issues, divergences and the search for middle ground. Reviews in Fish Biology and Fisheries 2001;11(3):197-216.

[5] Wilson J. Scientific uncertainty, complex systems and the design of common-pool institutions. Chapter 10 in Ostrom et al.[6], 2002, p. 327-359.

[6] Ostrom E, Dietz T, Dolšak N, Stern PC, Sonich S and Weber EU, editors. The Drama of the Commons. Washington, DC: National Academy Press, 2002.

[7] Dolšak N and Ostrom E, editors. The commons in the new Millennium. Cambridge, MA: MIT Press, 2003.

[8] Roberts CM and Hawkins JP. Fully-protected marine reserves: a guide. Washington DC: WWF, 2000. www.panda.org/downloads/marine/marinereservescolor.pdf

[9] 50 key facts about seas and oceans: www.unep.org/wed/2004/Downloads/PDFs/Key_Facts_E.pdf. UNEP World Environment Day 2004: Wanted! Seas and Oceans: Dead or Alive? Index of all reports www.unep.org/wed/2004/Information_Material/index.asp

[10] Pauly D, Christensen V, Guénette S, Pitcher TJ, Sumaila UR, Walters CJ, Watson R and Zeller D. Towards sustainability in world fisheries. Nature 2000;418(6898):689-695.

[11] Recommendations of the Vth IUCN World Parks Congress, Durban, South Africa. www.iucn.org/themes/wcpa/wpc2003/pdfs/outputs/recommendations/approved/english/pdf/r22.pdf.

[12] Suzuki D. A look at world parks. Science 2003;301(5638):1289.

[13] World Summit on Sustainable Development: Plan of Implementation: www.johannesburgsummit.org/html/documents/summit_docs/2309_planfinal.htm;

[14] Marine Conservation Biology Institute 1998. Troubled Waters: a call for action. www.mcbi.org/AboutUs/TroubledWaters.pdf

[15] Holmes B. Dreams as big as an ocean. New Scientist 1997;155(2097):20. News article concerning the initiative that led to the 20% call [14].

[16] National Centre for Ecological Analysis and Synthesis. Scientific consensus statement on marine reserves and protected areas. Journal of International Wildlife Law and Policy 2001; 4(1):87-90. www.nceas.ucsb.edu/Consensus

[17] Lubchenco J, Palumbi SR, Gaines SD, Andelman S. Plugging a hole in the ocean: the emerging science of marine reserves. Ecological Applications 2003;13(1) Supplement: S3-S7. Introduces 16 papers on various aspects of marine reserve design.

[18] Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ and Warner RR. Historical overfishing and the recent collapse of coastal ecosystems. Science 2003;293(5530):629-638.

[19] Jennings S and Kaiser MJ. The effects of fishing on marine ecosystems. Advances in Marine Biology 1998;34:203-352.

[20] Myers RA and Worm B. Rapid worldwide depletion of predatory fish communities. Nature 2003;423(6937:280-283.

[21] Pauly D and Christensen V. Primary production required to sustain global fisheries. Nature 1995;374:255-257.

[22] Reid PC, Battle EJV, Batten SD and Brander KM. Impacts of fisheries on plankton community structure. ICES Journal of Marine Science 2000;57:495-502.

[23] Thrush SF and Dayton PK. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annual Review of Ecology and Systematics 2002;33:449-473.

[24] Botsford LW, Castilla JC and Peterson CH. The management of fisheries and marine ecosystems. Science 1997;277:509-515.

[25] Murray SN, Ambrose RF, Bohnsack JA, Botsford LW, Carr MH, Davis GE, Dayton PK, Gotshall D, Gunderson DR, Hixon MA, Lubchenco J, Mangel M, MacCall A, McArdle DA, Ogden JC, Roughgarden J, Starr RM, Tegner MJ and Yoklavich MM. No-take reserve networks: sustaining fishery populations and marine ecosystems. Fisheries 1999;24(11):11-25.

[26] Palumbi SR. Marine reserves: a tool for ecosystem management and restoration. Washington DC: Pew Oceans Commission, 2003.

[27] Pauly D, Christensen V, Dalsgaard J, Froese R and Torres F. Fishing down marine food webs. Science 1998;279(5352):860-863.

[28] Roberts CM. Ecological advice for the global fisheries crisis. Trends in Ecology and Evolution 1997;2(1):35-38.

[29] Roberts CM and Hawkins JP. Extinction risk in the sea. Trends in Ecology Evolution 1999; 14(6):241-246.

[30] Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ and Doherty PA. Collapse and conservation of shark populations in the Northwest Atlantic. Science 2003;299:389-392.

[31] Stevens JD, Bonfil R, Dulvey NK and Walker PA. The effects of fishing on sharks, rays and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES Journal of Marine Science 2000;57(3):476-494.

[32] Spotila JR, Reina RD, Steyermark AC, Plotkin PT and Paladini FV. Pacific leatherback turtles face extinction. Nature 2000;405:529-530.

[33] Dalton R. Net losses pose extinction risk for porpoise. Nature 2004;429:590.

[34] Perrin WF, Donovan GP and Barlow J, editors. Cetaceans and gillnets. Cambridge: International Whaling Commission, 1994.

[35] Verhulst S, Oosterbeek K, Rutten AL and Ens BJ. Shellfish fishery severely reduces condition and survival of Oystercatchers despite creation of large marine protected areas. Ecology and Society 2004;9(1):17. www.ecologyandsociety.org/vol9/iss1/art17

[36] Guénette S, Lauck T and Clark C. Marine reserves: from Beverton and Holt to the present. Reviews in Fish Biology and Fisheries 1998;8(3):251-272.

[37] Guénette S and Pitcher TJ. An age structured model showing the benefits of marine reserves in controlling overexploitation. Fisheries Research 1999;39:295-303.

[38] Halpern BS, Gaines SD and Warner RR. Confounding effects of the export of production and the displacement of fishing effort from marine reserves. Ecological Applications 2004;14(4):1248-1256.

[39] Hastings A and Botsford LW. Equivalence in yield from marine reserves and traditional fisheries management. Science 1999;284(5419):1537-1538.

[40] Neubert MG. Marine reserves and optimal harvesting. Ecological Letters 2003;6:843-849.

[41] Nowlis JS and Roberts CM. Fisheries benefits and optimal design of marine reserves. Fisheries Bulletin 1999;97(3):604-616.

[42] Pezzey JCV, Roberts CM and Urdal BT. A simple bioeconomic model of a marine reserve. Ecological Economics 2000;33:77-91.

[43] Sumaila UR and Charles AT. Economic models of marine protected areas: an introduction. Natural Resource Modeling 2003;15(3):261-272. Introduces 10 papers in special edition

[44] Halpern B. The impact of marine reserves: do reserves work and does reserve size matter? Ecological Applications 2003;13(1):S117-S137.

[45] Halpern BS and Warner RR. Marine reserves have rapid and lasting effects. Ecology Letters 2002;5(3):361-366.

[46] Willis TJ, Millar RB and Babcock RC. Protection of exploited fish in temperate regions: high density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand marine reserves. Journal of Applied Ecology 2003;40:214-227.

[47] Gell FR and Roberts CM. Benefits beyond boundaries: the fishery effects of marine reserves. Trends in Ecology and Evolution 2003;18(9):448-455. Full report available at www.worldwildlife.org/oceans/pubs.cfm - The Fishery Effects of Marine Reserves and Fishery Closures.

[48] Roberts CM, Bohnsack JA, Gell F, Hawkins JP and Goodridge R. Effects of marine reserves on adjacent fisheries. Science 2001;294(5548):1920-1923.

[49] Shipp RL. A perspective on marine reserves as a fishery management tool. Fisheries 2003;28(12):10-20.

[50] Steele JH and Beet AR. Marine protected areas in 'nonlinear' ecosystems. Proceedings of the Royal Society of London B 2003;270: S230-233.

[51] Marine reserves: the best option for our oceans? Forum; Frontiers in Ecology and the Environment 2003;1(9):495-502.

[52] Carr M, Dayton P, Gaines S, Hixon M, Leonard G, Palumbi S and Warner R. Comments on ASA report entitled "No take marine protected areas (nMPAs) as a fishery management tool, a pragmatic perspective" by Robert L Shipp, PhD. www.compassonline.org/rebuttal_to_ASA.pdf, 2002.

[53] Polunin NVC. Marine protected areas, fish and fisheries. In: Hart PJB and Reynolds JD, editors. Handbook of Fish and Fisheries, Volume II. Oxford, UK: Blackwell Science, 2002, p. 293-318.

[54] Ballantine WJ. The New Zealand experience with 'no-take' marine reserves. In: Roberts C, Ballantine WJ, Buxton CD, Dayton P, Crowder LB, Milon W, Orbach MK, Pauly D and Trexler J, Editors. Review of the use of marine fishery reserves in the US Southeastern Atlantic. NOAA Technical Memorandum NMFS-SEFSC-376, 1995, C15-C31. Cited in Roberts [28]

[55] Ostrom E. Governing the commons: the evolution of institutions for collective action. Cambridge: Cambridge University Press, 1990.

[56] Ostrom E. A behavioural approach to the rational choice theory of collective action. American Political Science Review 1998;92(1):1-22.

[57] Ostrom E. Coping with tragedies of the commons. Annual Review of Political Science 1999;2:493-535.

[58] Castilla JC and Defeo O. Latin American benthic shellfisheries: emphasis on co-management and experimental practices. Reviews in Fish Biology and Fisheries 2001;11(1):1-30.

[59] Domínguez-Torreiro M, Freijeiro-Àlvaraz AB and Iglesias-Malvido C. Co-management proposals and their efficiency implications in fisheries management: the case of the Grand Sole fleet. Marine Policy 2004;28(3):213-219.

[60] Galal N, Ormond RFG and Hassan O. Effects of a network of no-take reserves in increasing catch per unit effort and stocks of exploited reef fish at Nabq, South Sinai, Egypt. Marine and Freshwater Research 2002;53(2):199-205.

[61] Mahon R, Almerigi S, McConney P, Parker C and Brewster L. Participatory methodology used for sea urchin management in Barbados. Ocean & Coastal Management 2003;46(1-2):1-25.

[62] Nielsen JR and Vedsmand T. User participation and institutional change in fisheries management: a viable alternative to the failures of 'top-down' driven control? Ocean & Coastal Management 1999;42:19-37.

[63] Nielsen JR, Degnbol P, Viswanathan KK, Ahmed M, Hara M and Abdullah NMR. Fisheries co-management - an institutional innovation? Lessons from South East Asia and Southern Africa. Marine Policy 2004;28(2):151-160.

[64] Pomeroy RS and Berkes F. Two to tango: The role of government in fisheries co-management. Marine Policy 1997:21(5):465-480.

[65] Pomeroy RS, Katon BM and Harkes I. Conditions affecting the success of fisheries co-management: lessons from Asia. Marine Policy 2001;25:197-208.

[66] Wilson DC, Nielsen JR and Degnbol P, editors. The fisheries co-management experience: accomplishments, challenges, and prospects. Kluwer Fish and Fisheries Series 26. Dordrecht: Kluwer Academic Publishers, 2003.

[67] Hilborn R, Punt AE and Orensanz J. Beyond band-aids in fisheries management: fixing world fisheries. Bulletin of Marine Science 2004;74(3):493-507.

[68] Gell FR and Roberts CM. Marine reserves for fisheries management and conservation: a win-win strategy. El Anzuelo: European Newsletter on Fisheries and the Environment 2003;11:4-6. www.ieep.org.uk/PDFfiles/PUBLICATIONS/El%20Anzuelo/ElAnz11_GB.pdf

[69] Seeking the win-win situation: a brief guide to balancing conservation and fisheries yields in reserve design. MPA News 2003/2004;5(6):1-2. depts.washington.edu/mpanews/MPA48.htm#win-win

[70] Ballantine WJ. MPA Perspective: MPAs improve general management, while marine reserves ensure conservation. MPA News 2002;4(1):5. depts.washington.edu/mpanews/MPA32.htm#Ballantine

[71] NFCC (National Fisheries Conservation Center) Consensus statement on integrating marine reserve science and fisheries management, 2004. nfcc-fisheries.org/consensus/index.php

[72] Hastings A and Botsford LW. Comparing designs of marine reserves for fisheries and for biodiversity. Ecological Applications 2003;13(1):S65-S70.

[73] Roberts CM. Selecting marine reserve locations: optimality versus opportunism. Bulletin of Marine Science 2000;66(3):581-592.

[74] Simberloff D. No reserve is an island: marine reserves and nonindigenous species. Bulletin of Marine Science 2000;66(3):567-580.

[75] Fanshawe S, VanBlaricom GR and Shelly AA. Restored top carnivores as detriments to the performance of marine protected areas intended for fishery sustainability: a case study with red abalones and sea otters. Conservation Biology 2003;17(1):273-283.

[76] Predation in marine reserves: how increases in predator populations can impact diversity and fisheries goals. MPA News 2004;6(1):1-3. http://depts.washington.edu/mpanews/MPA54.htm#predation

[77] Béné C and Tewfick A. Biological evaluation of marine protected area: evidence of crowding effect on a protected population of Queen Conch in the Caribbean. Marine Ecology 2003;24(1):45-58.

[78] Agardy T, Bridgewater P, Crosby MP, Day J, Dayton PK, Kenchington R, Laffoley D, McConney P, Murray PA, Parks JE and Peau L. Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. Aquatic Conservation 2003;13(4):353-367.

[79] Callicot JB. Conservation ethics and fishery management. Fisheries 1991;16(2):22-28.

[80] Miller ML and Kirk J. Marine environmental ethics. Ocean & Coastal Management 1992;17(3/4):237-251.

[81] Agrawal A. Common property institutions and sustainable governance of resources. World Development 2002;29(10):1649-1672

[82] Baland JM and Platteau JP. Halting degradation of natural resources: is there a role for rural communities? Oxford: Clarendon Press, 1996.

[83] Ludwig D, Hilborn R and Walters C. Uncertainty, Resource Exploitation, & Conservation: Lessons from History. Science 1993;260(5104)17-36.

[84] Charton JAG and Ruzafa PA. Ecological heterogeneity and the evaluation of the effects of marine reserves. Fisheries Research 1999;42(1-2):1-20.

[85] Charton JAG, Williams ID, Ruzafa AP, Milazzo M, Chemello R, Marcos C, Kitsos MS, Koukouras A, Riggio S. Evaluating the ecological effects of Mediterranean marine protected areas: habitat, scale and the natural variability of ecosystems. Environmental Conservation 2000;27(2):159-178.

[86] Lauck T, Clark CW, Mangel M and Munro GR. Implementing the precautionary principle in fisheries management through marine reserves. Ecological Applications 1998;8(1):S72-S78.

[87] Dayton PK. Reversal of the burden of proof in fisheries management. Science 1998;279:821-822.

[88] Auster PJ and Langton RW. The effects of fishing on fish habitat. American Fisheries Society Symposium 1999;22:150-187.

[89] Kaiser MJ, Spence FE and Hart PJB. Fishing-gear restrictions and conservation of benthic habitat complexity. Conservation Biology 2000;14(5):1512-1525.

[90] Johannes RE, Freeman MMR and Hamilton RJ. Ignore fishers' knowledge and miss the boat. Fish and Fisheries 2000;1(3):257-271.

[91] Mackinson S. Integrating local and scientific knowledge: an example in fisheries science. Environmental Management 2001;27(4):533-545.

[92] Neis B, Schneider DC, Felt L, Haedrich RL, Fischer J and Hutchings JA. Fisheries assessment: what can be learned from interviewing resource users? Canadian Journal of Fisheries and Aquatic Sciences 1999;56(10):1949-1963.

[93] Barnes B, Bloor D and Henry J. Scientific knowledge: a sociological analysis. Chicago: University of Chicago Press, 1996.

[94] Dietz T and Stern PC. Science, values and biodiversity. Bioscience 1998;48(6):441-444.

[95] Ravetz JR. What is post-normal science? Futures 1999;31(7):647-653.

[96] Roberts CM. Enforcing no take zones. Marine Conservation 2003;6(1):12-13. Ross-on-Wye, UK: Marine Conservation Society.

[97] Christie P, McCay, BJ, Miller ML, Lowe C, White AT, Stoffle R, Fluharty DL, McManus LT, Chuenpagdee R, Pomeroy C, Suman DO, Blount BG, Huppert D, Eisma RLV, Oracion E, Lowry K and Pollnac RB. Toward developing a complete understanding: a social science research agenda for marine protected areas. Fisheries 2003;28(12):22-26.

[98] Lubchenco J. Entering the Century of the environment: a new social contract for science. Science 1998;279:490-497.

[99] Myers N. Environmental scientists: advocates as well? Environmental Conservation 1999;26(3):163-165.

[100] Mackey BG. Environmental scientists, advocacy, and the future of the Earth. Environmental Conservation 1999;26(4):245-249.

[101] Hilborn R, Stokes K, Maguire J, Smith T, Botsford LW, Mangel M, Orensanz J, Parma A, Rice J, Bell J, Cochrane KL, Garcia S, Hall SJ, Kirkwood GP, Sainsbury K, Stefansson G and Walters C. When can marine reserves improve fisheries management? Ocean & Coastal Management 2004;47(3/4):197-205.

[102] Norse EA, editor. Global marine biological diversity: a strategy for building conservation into decision making. Washington DC: Island Press, 1993, p. 37-86.

[103] Jameson SC, Tupper MH and Ridley JM. The three screen doors: *can* marine "protected" areas be effective? Marine Pollution Bulletin 2002;44(11):1177-1183.

[104] Soto CG. The potential impacts of global climate change on marine protected areas. Reviews in Fish Biology and Fisheries 2001;11(3):181-195.

[105] Estes JA, Tinker MT, Williams TM and Doak DF. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science 1998;282:473-476.

[106] Berkes F. Cross-scale institutional linkages: perspectives from the bottom up. Chapter 9 in Ostrom et al. [6], 2002, p. 293-321.

[107] Borrini-Feyerabend G. Collaborative management of protected areas. In: Stolton S and Dudley N, editors. Partnerships for Protection: new strategies for planning and management for protected areas. London: Earthscan, 1999, p. 225-234.

[108] Rydin Y and Pennington M. Public participation and local environmental planning: the collective action problem and the potential of social capital. Local Environment 2000;5(2):153-169.

[109] Murphree MW. The role of institutions in community-based conservation. In: Western D, Wright RM and Strum SC. Natural Connections: perspectives in community-based conservation. Washington DC: Island Press, 1994, p. 403-427.

[110] Erwin DG. Strangford Lough – 40+ years of loss of biodiversity under conservation management. In proceedings: Coastal Futures 2003: review and future trends. Ross-on-Wye, Gloucestershire: Coastal Management for Sustainability, 2003. www.coastms.co.uk

[111] Jones PJS and Burgess J. Building partnership capacity for the collaborative management of marine protected areas in the UK: a preliminary analysis. Journal of Environmental Management (accepted subject to revisions).

[112] Kelleher G. Guidelines for marine protected areas. Gland: IUCN, 1999.

[113] Dryzek JS. Rational ecology: environment and political economy. Oxford, UK: Basil Blackwell, 1987. Cited in Milon [114]

[114] Milon JW. Pastures, fences, tragedies and marine reserves. Bulletin of Marine Science 2000;66(3):901-906.

[115] Davis KLF, Russ GR, Williamson DH and Evans RD. Surveillance and poaching on inshore reefs of the Great Barrier reef Marine Park. Coastal Management 2004;32(4):373-387.

[116] Anon. MPA enforcement: practitioners employ a mix of high-tech and community-based strategies. MPA News 2000;2(5):1-3. depts.washington.edu/mpanews/MPA14.htm#Enforcement

[117] Causey BD. Enforcement in marine protected areas. In: Gubbay S, editor. Marine Protected Areas: principles and techniques for management. London: Chapman and Hall, 1995, p. 119-148.

[118] Ballantine WJ. Marine reserves: lessons from New Zealand. Progress in Underwater Science 1989;13:1-14.

[119] Sant M. Environmental sustainability and the public: responses to a proposed marine reserve at Jervis Bay, New South Wales, Australia. Ocean & Coastal Management 1996;32(1):1-16.

[120] Anon. Financial support for fishermen who are affected by marine reserves: examining the merits. MPA News 2002;3(11):1-3. depts.washington.edu/mpanews/MPA31.htm#compensation

[121] Jones PJS. Marine nature reserves in Britain: past lessons, current status and future issues. Marine Policy 1999;23(4-5):375-396.

[122] Davis C. The Lyme Bay reefs project – two years and two reefs. Marine Conservation 2001;5(5):22. Ross-on-Wye, UK: Marine Conservation Society.

[123] Owens S. 'Engaging the public': information and deliberation in environmental policy. Environment and Planning A 2000;32:1141-1148.

[124] Jones PJS, Burgess J and Bhattachary D. (2001) An evaluation of approaches for promoting relevant authority and stakeholder participation in European marine sites in the UK. Peterborough: English Nature (UK Marine SACs Project), 2001. www.homepages.ucl.ac.uk/~ucfwpej/icem.htm#MSAC

[125] Kritzer JP. Effects of non-compliance on the success of alternative designs of marine protected-area networks for conservation and fisheries management. Conservation Biology 2004;18(4):1021-1031.

[126] Cooke SJ and Cowyx IG. The role of recreational fishing in global fish crises. Bioscience 2004;54(9):857-859.

[127] Denny CM and R. C. Babcock RC. Do partial marine reserves protect reef fish assemblages? Biological Conservation 2004;116(1):119-129.

[128] Westera W , Lavery P and Hyndes G. Differences in recreationally targeted fishes between protected and fished areas of a coral reef marine park. Journal of Experimental Marine Biology and Ecology 2003;294(2):145-168.

[129] Helvey M. Seeking consensus on designing marine protected areas: keeping the fishing community engaged. Coastal Management 2004;32(2):173-190.

[130] Scholz A, Bonzon K, Fujita R, Benjamin N, Woodling N, Black P and Steinbeck C. Participatory socioeconomic analysis: drawing on fishermen's knowledge for marine protected area planning in California. Marine Policy 2004;28(4):335-349.

[131] Weible C, Sabatier PA and Lubell M. A comparison of a collaborative and top-down approach to the use of science in policy: establishing marine protected areas in California. The Policy Studies Journal 2004;32(2):187-207.

Table 1 Summary of arguments of proponents and opponents of NTZs for fisheries conservation

Many fish stocks are overfished/depleted and MFMAs have evidently failed [25, 28, 36]	A small proportion of fish stocks are actually overfished/depleted and these are generally the result of previous poor decisions. MFMAs remain the best means of fisheries management [49, 51], particularly bottom-up rights-based approaches [67]
NTZs can accelerate the recovery of depleted fish stocks [25]	NTZs may be appropriate for the recovery of severely depleted and isolated stocks where there is a low capacity for MFMAs, otherwise MFMAs will be more effective [49]
NTZs will improve fish stocks within their boundaries [44]	Many reports of such increases scientifically ambiguous [3]
NTZs will lead to spillover of adults which will improve adjacent fisheries [47, 48]	NTZs will only improve sedentary stocks, the low mobility of which will minimise export [49]. Designation of NTZs will generally require quotas to be reduced [49, 51]. Effort displacement to stocks outside NTZs could actually have wider negative impacts [51].
NTZs will lead to export of larvae which will also improve adjacent fisheries [28, 36]	Larval production is not generally a critical limiting factor in recruitment; density-dependent factors far more important [49, 51].
NTZs important for critical habitats, e.g. fish spawning, feeding, migratory & nursery areas [102]	These are usually seasonal so temporary closures can be as effective as permanent closures, avoiding year-round loss of fishing grounds [49]. Effort displacement to critical habitats outside NTZs could actually have wider negative impacts [51].
NTZs an important ecosystem restoration and protection tool [26, 51]	NTZs ideal for restoring ecosystem equilibrium but then MFMAs which provide for sustainable yield more appropriate [49]. Possible that NTZs could have negative ecological impacts on fisheries [51]
NTZs are a precautionary approach to fisheries management, providing insurance in the face of uncertainty [25, 36, 86]	Argument that NTZs can provide more precaution against uncertainty than MFMAs is currently an unproven assertion [71]. MFMAs can become more precautionary by setting more conservative harvest levels and improving our knowledge of fisheries dynamics, which will also reduce uncertainty [49].
Models predict that NTZs will increase the size and sustainable yield of fish populations [36, 39, 40, 43], and that they will also reduce size/yield variability [37, 41, 42]	Evidence from models debatable as they are based on simplistic assumptions[3] and other modellers indicate that effort reduction will be more effective than NTZs [50]
Unregulated stocks sympatric with target stocks will be conferred protection by NTZs [51]	NTZs will reduce the harvest potential of unregulated sympatric stocks which are otherwise sustainable [49]