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DESIGN PRINCIPLES FOR SYSTEMS OF 'NO-TAKE' MARINE RESERVES

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SUMMARY

Systems of 'no-take' marine reserves will have emergent properties, which will give them broader and more important values than can exist for single reserves. 'No-take' reserve systems can be made self-sustaining, supportive of total ecosystem dynamics and helpful in the management of harvested species. The creation of such systems does not require detailed survey data or calculations of cause and effect. The principles for such systems would be: representation, replication, and a network design. The area required would be ~ 20-30% of the total.

At present the creation of 'no-take' marine reserves is localised, analytical and sectorial. This approach requires scientists to make detailed predictions about the benefits of particular reserves before they are established, and leaves politicians to decide what principles should guide the whole process. This role-reversal produces a lot of confusion but very little action.

Despite this, existing examples of 'no-take' marine reserves' and widely-accepted biological principles show how the situation could be improved. Scientists should focus on developing the principles, defining the natural constraints, exploring the interactions of these for systems of 'no-take' reserves and expressing the consequences in clear terms to the general public. The priority order, rate of implementation, and precise location of reserves should be left to the politicians and the democratic process. When these roles are restored, it will become clear that the establishment of systems of 'no-take' marine reserves is scientifically necessary, politically practical, economically sensible and socially desirable.

Creating *systems* of marine reserves, using the emergent principles, greatly simplifies decision-making both scientifically and politically. For scientists, difficult distinctions at one level translate into major decisions at the next. The principle of representation means that border-line biogeographic distinctions are easily handled as major ecological decisions. Problematic ecological differences can be subsumed in straightforward replication. Subtle difficulties with replication become simple decisions in

network design. Most problems with network design are settled by a decision in principle on the total amount. Furthermore, when representation, replication and a network design are accepted as scientific principles, there is no need to acquire detailed data to calculate ‘priorities’. The available information is quite sufficient to recommend action.

Politicians are accustomed to arranging the priorities and details of action, including handling local and sectional interests, but can only do so effectively when clear and important principles are at stake. The *general* public will give active support to sensible principles, whereas one-by-one approaches attract little attention except from those adversely affected.

INTRODUCTION:

Science, like politics, is based on actual events, particular experiments and real observations. Useful principles in either are not generated by pure thought. However progress in both subjects depends on the translation of actual experience into principles. At some stage, we recognise that wheels should be round and cease to investigate all the possible shapes.

There are now many 'no-take' marine reserves. They have been tried in many countries (socio-political variation) and in many regions (biogeographic variation). Many different habitats are included (ecological variation) and there is a wide range of sizes and administrative systems. There are enough cases to consider the principles.

In this paper, marine reserves are defined as areas of the sea with no fishing or extractions of any kind, where all other forms of human disturbance are minimised, but where people are encouraged to visit, observe and study the more natural life and processes. All other types of marine protected areas (such as temporary or partial closures) are part of 'standard' fisheries management. 'Standard' management (mostly stock-specific, data-based 'problem-solving) will continue to operate. 'No-take' marine reserves are a new and *additional* form of management (Ballantine, 1996). The actual benefits of 'no-take' reserves to resource management are not covered here, since these have been discussed elsewhere (e.g. Plan Development Team, 1990; Ballantine 1991, 1994 and 1995; Bohnsack, 1996; Roberts, 1997). This paper is primarily concerned with the appropriate principles for the design of systems of such reserves.

The key concept here is *systems*. A great deal has been written about the actual or likely effects of single marine reserves on the nearby areas, particular stocks or specific activities (e.g. Roberts and Polunin 1991; Rowley, 1994, Russ and Acala, 1996,). So far, however, little attention has been given to the overall effects of systems of marine reserves. ‘Overall’ in this context means long-term (>10 years), large areas (whole biogeographic regions) and all species and their interactions (ecosystem dynamics).

There are good reasons to suppose that the most important benefits from creating systems of ‘no-take’marine reserves will derive from ‘system effects’ -i.e. emergent properties which are not measurable or even readily appreciated when analysing single reserves. Mathematical theory and general experience suggest that systems (even when composed of simple units) will have emergent properties, and that these will be large, important and relatively easy to predict without detailed data. This is true for natural systems (physical and biological) and human systems (socio-economic). Systems of 'no-take' marine reserves will have two levels of emergent properties. Not only will there be systems effects at physical, biological and human levels, but these will then interact.

One of the more likely emergent properties on the socio-political level is that, after minimal trials (such as have already occurred in New Zealand and elsewhere), it will be easier to approach marine reserves in principle. A general policy for an effective system, based on clear principles, is more likely to receive general public support than specific proposals, however carefully-crafted and argued. This point is the reverse face of 'NIMBY' (not in my backyard). Local opposition to particular proposals based on actual inconvenience or economic loss cannot be reduced, but it is diluted to non-critical levels by widespread public agreement on a general policy.

At present, the approach to 'no-take' marine reserves is very localised, highly analytical and almost entirely related to sectional interests. There is little discussion of broad principles (either scientific or social) and few attempts to investigate effects above the level of single reserves. As a result scientists find themselves trying to make what are, in fact, political decisions (E.g. *Which habitats should be included in the* ***first*** *reserve?* or *Would this proposed reserve produce benefits popular enough to justify its establishment?*). Worse still, while the scientists are deeply involved in what are really social details, the politicians are left to decide what broad principles should guide the whole process.

This role-reversal, not surprisingly, produces a great deal of confusion but inhibits much action.The solution is relatively simple. We need to restore each profession to its proper role.This can be done, but it requires both scientists and politicians to follow a chain of reasoning to its conclusions.

The chain of reasoning (see General Argument) consists of well-established facts, simple deductions, and generally-agreed principles. In theory, following the chain to its conclusions should be straight-forward. In fact, there are three serious problems. The first is that the chain of reasoning is rather long, and it is easy to give up or become side-tracked before reaching the conclusions. The second is that the conclusions are very different from existing assumptions and require actions very different from present standard practise. This makes experienced professionals (both scientists and politicians) very cautious, if not actually hostile. Furthermore the length of the reasoning chain gives ample opportunity for denial, nit-picking or red herrings.

The third problem is one of scale. Systems of marine reserves will cover large areas, be permanent and have broad effects. There are no existing models. Most established 'no-take' reserves are small, recent, or specialised in intent. If systems of 'no-take' marine reserves are to be created, scientists will have to use basic principles and work out the general consequences by conducting 'thought experiments,' instead of calculating particular results from detailed data. The politicians will have to shift some consideration to the long-term and general public interest, instead of just looking at the effects on existing local user groups.

In this paper, I will state the ‘chain of reasoning’ for systems of marine reserves and document this in the usual way. In addition, to reduce the problems mentioned above, I will try to:
(a) State the conclusions early on, so that the direction of the argument can be appreciated more easily.
(b) Show that similar chains of reasoning are already accepted and used in analagous situations, both scientifically and politically.
(c) Give real examples of how the conclusions might be translated into action.
(d) Demonstrate that most sections of the argument for ‘no-take’ marine reserves have already been stated by experts in their respective fields, although these are rarely joined up to reach the full conclusions.

HISTORICAL BACKGROUND:

Many countries have created ‘no-take’ marine reserves during the past 30 years, but this fact is difficult to document accurately. There is no agreement about the labels. British ‘marine reserves’ and US ‘marine sanctuaries’ allow fishing as usual, unless additional and specific regulations are made. Furthermore, most of the literature is concerned with ‘marine protected areas’ (MPAs), which turn out to be any piece of the sea with some special regulations.

It is clear, however, that no full and proper systems of 'no-take' marine reserves have been established so far. In some countries marine reserves already cover a range of regions and habitats. South Africa has many 'marine reserves', including some large ones. But only 8 are 'no-take' (Attwood and Bennett, 1995) and since their designation lacked full democratic process, their future is in doubt. New Zealand has 12 'no-take' reserves scattered around the country (Department of Conservation, 1995) and more are promised by the major political parties. But the existing reserves had a wide variety of reasons and sponsors, and, as yet, there is no clear policy governing the establishment of further reserves.

In a few regions, systems of ‘no-take’ marine areas have been proposed, but are not yet established e.g. for the south-east USA (Plan Development Team, 1990) ; Western Australia (Department of Conservation, 1994) and Victoria, Australia (Land Conservation Council, 1996). Even these proposed systems are limited in purpose, (e.g. ‘reef fisheries management’ in southeast USA), are merely one zone in a more complex planning scheme (e.g. Western Australia) or both (e.g. Victoria).

Some attention has been given to the actual or potential effects on whole fisheries, especially in S. Africa (e.g. Buxton, 1994) and the South-east USA (Roberts *et al*, 1995), but the establishment and proposal of ‘no-take’ marine areas has been dominated by local and highly-selective concerns. This is especially true in third-world countries, e.g. in Belize (Roberts and Polunin, 1994), Phillipines (Russ and Acala, 1994), and Kenya (McClanahan and Shafir, 1990) .

In the more affluent world, most existing ‘no-take’ marine areas were created for reasons unrelated to fisheries - such as (with New Zealand examples):

research by adjacent marine laboratories	(Leigh)
recreational diving and tourist promotion	(Poor Knights)
high-profile species	(Fiordland)
unique biological features	(Kermadecs)

Consequently, despite the range of examples of ‘no-take’ marine reserves (many countries, biogeographic regions, ecological habitats, etc.), if we wish to consider the principles for systems of such reserves there are no models to copy or fully-suitable proposals to test. This is, of course, more daunting to politicians and administrators than to scientists, but since politicians will have to make the final decisions, and administrators will formulate the actual proposals, it is an important consideration.

GENERAL ARGUMENT:

Traditionally management in the sea has been highly fragmented in several ways. Different countries and their provinces had quite different regulations. Within a country there were many separate and unocordinated regulatory agencies. Most regulations were designed to solve particular problems as these arose (or were noticed). The whole process lacked any widely-agreed principles.

General marine planning - a unified, multi-purpose, proactive exercise based on principles - began late in the sea, but is now proceeding with increasing rapidily. To be practical, general planning must be based on agreed, easy to understand and reasonably stable. It is usually expressed as a set of mapped zones in which only compatable activities are allowed, and revisions of rules and boundaries are not frequent.

Marine reserves (‘no-take’, minimally-disturbed areas of the sea where people are welcomed) fit the basic criteria for good general planning. The principles are clear, the concept is simple to understand, the reserves are permanent and they support a variety of important and compatable uses. Although still relatively rare, such reserves have a good claim for priority in general marine planning (i.e. to be the first multi-use zone in the sea). But so far, if they exist at all, they are tacked on at a late stage. Freedom of activity in the sea, until problems arise, is still the most commonly-accepted idea, although it is an historical accident unsupported by facts, experience or theory, and is becoming steadily less popular.

‘No-take’ marine reserves provide clear benefits to science, education, recreation, general management and conservation. As a result, it is likely that many countries will

develop a system of them in the near future. Optimising the known benefits of ‘no-take’ marine reserves would require the system to be:
(a) representative - biogeographically and ecologically
(b) replicated for scientific, general management and social reasons.
(c) ‘networked’ to promote self-sustainability by larval dispersal and
(d) to comprise at least 10% by area (of all habitats in all regions).

Since systems of ‘no-take’ areas are likely, the question for fisheries scientists and managers is how to arrange and/or extend systems to provide optimal benefit for fisheries. (Note that the closure of certain areas to fishing for *particular* stocks or species is part of standard fisheries management, which will continue to operate. The system of ‘no-take’ areas is a new, different and *additional* management tool.)

Most of the principles required to maximise benefits for scientific and social purposes are the *same* as those needed to maximise the benefits to fisheries and for basically the same reasons. The probable exception to this is the total area of ‘no-take’. For optimum benefit to wild-stock fisheries this is likely to be several times greater than could reasonably satisfy other uses of the system.

Consequently it is sensible for fisheries interests to encourage 'no-take' marine reserve systems and to promote their extension. This would require broader considerations than are normally present in stock-specific management, but would gain active political support from a wide section of the general public.

PRINCIPLES FOR SYSTEMS OF 'NO-TAKE' MARINE RESERVES

A. METAPRINCIPLES

1. We must allow for ignorance, not just rely on existing knowledge.

This incorporates the 'precautionary principle' as usually stated for particular problems, but is even more fundamental. Not only is our knowledge insufficient to calculate solutions to all our problems, it is unlikely that we know all the problems. The potentially most serious problems may not have occurred yet.

2. The sea can and will 'naturally' manage itself, if we let it.

Although our power of disruption is great and increasing, natural processes still dominate in the sea. In most terrestrial situations, the idea of 'natural' (meaning without influence by humans) is of limited value, if not actually meaningless, because of lengthy co-evolution of humans and their environment. In the sea, however, the concept of 'natural' is not only objective, it is necessary. Our power of positive control over marine processes is still weak or non-existent.

3. Marine reserves must be as natural as possible, and be seen to be so.

Marine reserves must be as natural as we can arrange. No killings, no extractions and as little other disturbance as we can reasonably arrange. This is necessary for scientific, management and social reasons. It is not sufficient to regulate human activities separately, we need to know total effects as well as separate ones.
In one recent study the effects of trawling in the North Sea were 'controlled' by comparison with areas near gas/oil rigs (where trawling is not permitted), while another study 'controlled' the effect of gas/oil rigs on bottom fauna using stations well into the trawling areas. While the workers concerned did the best they could in the circumstances, this did not make it good science or a reliable basis for management decisions.

Although no area in the sea can be made completely natural (e.g. some pollutants are pervasive), we can and should strive to minimise all forms of interference in marine reserves. But it is also important that this be seen to be done. Public access to marine reserves needs encouragement, both as personal experience and vicariously through films, displays, etc. Some workers stress the 'damage' public access can do, but they ignore much more important points. Reserves will be decided by the democratic process. Reserve use for education and (non-extractive) recreation will be a critcal part of that process. In any case, while fish-feeding or seaweed trampling in reserves are unfortunate, they are insignificant in effects compared to harvesting and other disturbances normal in the sea. Scientific reserves that are closed to the public will be small and rare (as on the Great Barrier Reef), whereas reserves open to the public can be as large and common as the public desires.

4. Urgency

Time is not on our side. We always needed undisturbed pieces of the sea. To some extent we had them until our technologies improved, but every bit is accessible now and becoming more so each year. Pressures are increasing rapidly for other reasons - including all those associated with increasing population. Everything we know indicates that the longer we wait to create ‘no-take’ pieces of the sea, the more difficult it will be to do so (more users with more entrenched interests) and less we will benefit (more damage taking longer to restore). It is not sensible to delay.

5. These priniciples are a practical basis for public policy in a democracy

The four (meta)principles given above are fairly obvious to the general public. Indeed they are often better at appreciating these points than the experts, managers and user-groups, whose detailed and urgent interests often obscure basic points.

Not only can the *general* public 'see the forest despite the trees', they also form a permanent majority, compared to user groups. Consequently, it is politically and socially practical to base policy on these points. The key word is policy. Until recently non-users were assumed to be uninterested in the sea, but, while this may have been true, it is changing very rapidly. In any case, user-groups with vested interests often support sensible principles, even if they complain when these are applied to their disadvantage.

B. Scientific principles

1. Representation

This is the most important and fundamental principle. It is easy to understand, but it is so basic it is hard to state it without sounding pompous and pedantic. Although accepted by virtually everyone as a principle, it is ignored by most people (including scientists) when practical action is considered.

By definition, different biogeographic regions and different habitats have different biota, so examples of all regions and all habitats in each region must be included in a 'no-take' marine reserve system, simply to contain the range of species and habitats. Any omissions from this range, for any reason, is unjustifiable in scientific terms and is ‘playing God’ in ordinary terms. Full representation is the only way of ensuring the conservation of marine biodiversity and of having suitable scientific controls. All other benefits of a 'no-take' marine reserve system are optimised by complete representation.

In terrestrial biology, biogeography was a leading field of study in the last century and the classification of ecological habitats was very important in the first half of this century. Both subjects have ceased to have much allure. Even in marine biology, which developed later, biogeography and habitat classification are no longer exciting research frontiers. It is important to recognise the reasons for this. The first is simply that most, if not all, the major distinctions are now known, documented, accepted, built into theory and used in practise. The second is that finer distinctions, while possible, not only have fewer interesting applications, they are also increasingly arbitrary in their definitions and hence are theoretically suspect.

For present purposes, we should note that (a) the *major* distinctions in biogeography and ecology are well-known, and can be used with confidence but (b) *fine-scale* distinctions in both fields are likely to be arguable, even when well-documented, and, hence unsuitable for policy decisions.

When applying the principles of representation, replication etc. to the design of marine reserve systems, it is important (for practical and theoretical reasons) to recognise the following rules:

(a) The principles have an *order* (derived from their scale in spatial terms) - biogeographic considerations come before ecological ones, ecological distinctions apply before replication, and replication before network design.

(b) At each level decisions can be conservative, without *any* loss of effect. Border-line cases are easily dealt with at the next level (down) and if conservative decisions are more widely accepted.

(c) ‘Political’ boundaries and current notions of jurisdictionare not relevant. *Scientific* distinctions (and advice based on them) should blandly ignore these points. Existing administrations may well restrict *their* action to *parts* of the advice, that is their business, but the *advice* should not be altered or restricted by this.

2. Replication

There are at least three mutually-reinforcing reasons for 'replicates' in a marine reserve system - scientific, managerial and social.

(a) Formal analysis requires several equivalent instances to be considered - both for 'treatments' and 'controls' - not only so that variation can be measured, but also because single instances may demonstrate nothing but the possibility of occurence.

(b) Accidents - whether natural (e.g. severe storms) or human-induced (e.g. oil spills) - make it prudent to have more than one example of each case.

(c) Social use (e.g. education and recreation) is largely governed by access distance. Reserves of each type should match the distribution of people. If particular habitats are very popular, more reserves of that type will relieve pressure and improve benefits.

3. Network design

Most marine biota have small dispersive propagules in their life cycle, and in most populations recruitment is decoupled from reproduction. Since eggs and larvae are dispersed by the currents, often for considerable periods, *single* marine reserves are unlikely to be self-sustaining (unless they are very large).

Using a network design, a *system* of marine reserves can be made sustainable**.** and this will have two other practical advantages. Detailed information (about larval pathways, etc.) is not a requirement for such a system. The intervening spaces (i.e. the rest of the sea) will automatically be supported to some extent.

None of these points are obvious from the analysis of single stocks or single reserves, they are emergent properties of a system. The precise effect on any particular stock will still depend on the size of reserves and their spacing, but the direction of action (the sign) is predictable. (The analogy with fishing nets is quite useful. The geometric design of a net enables it to catch, but detailed effects are determined by the mesh size and the strength of its strings).

The most effective size and spacing of reserves will be inversely proportional to the ecological diversity at the scale of consideration. Marine ecological diversity on a scale of 1-10+ kilometres is generally proportional to the fractal form (in 2 or 3 dimensions). Where, due to high coastal indentation and/or rugged bottom topogrpahy, the fractal is high, the habitat diversity will also be high. To maintain representation and maximum interchange mesh' of a reserve network (i.e. the size and spacing of reserves) will be smaller when the fractal form is high.

The principle of a network is multiple and overlapping redundancy. Pathways are not designed or calculated one by one, they are systematically maximised. The actual route taken in an event is one of many. In a network, overall efficiency does not depend on optimising particulars, but by ensuring that all options are potentially open.

Single marine reserves are likely to produce increases in spawning biomass (via higher densities and larger sizes) and fertilisation rates (via increased densities) in many species. In combination, these are likely to enhance 'recruitment' somewhere down-current. The effect of a *network* of reserves is not just to add these ‘extra recruitments’ in some simple fashion, but to 'multiply' them in complex ways. Mathematicians and physicists have shown that networks have many remarkable properties. The overall results of these may be simple to observe, but extremely difficult to explain, calculate or predict in detail. The usual method of investigation is to use iterative models with relatively simple rules, but even then it is unwise to believe any conclusions without both some practical tests and a careful exploration of the constraints and boundary conditions. For example, the long series of computer model investigations into the 'evolution of cooperation' reversed its main conclusions several times - see Axelrod (1984) through Nowak *et al* (1996).

In a marine reserve network, it is not sufficient to consider the effect of one reserve, one species, or one current pattern but all of these, and all their variations over many years. It is not sensible to rely on conclusions from general, average or typical conditions. Small probabilies are likely to be important. In most fish populations the number of hatched larvae is an very small fraction of the spawning adults produced. This means that low probabilities rule. In most populations variation in recruitment between years is high. When a correlation is demonstrated with some environmental feature, this is regarded (quite properly) as valuable piece of research. This means that for most cases we have little or no information on what factors control the variation.

A network design for a marine reserve system fits what we know about marine populations and their methods of reproduction and recruitment. More importantly it allows for what we do not know.

4. The system must be large enough to be self-sustaining.

The scientific need for natural and undisturbed areas in the sea is permanent; and the social, managerial and conservation benefits from such areas will continue for the foreseeable future. It is therefore a fundamental requirement of a 'no-take' marine reserve system that it be sustained in a natural state (this includes natural variation). Since the rest of the sea will be subject to multiple extractions (and other actions with ptentially-detrimental effects) this means that the reserve system must be able to sustain *itself*, as far as possible independently of external events.

Although a network design of marine reserves is necessary to achieve sustainability, actual achievement of a self-sustainable state is dependent on total size (and the degree of 'general damage' outside). With a network design, the total size results from a combination of individual reserve sizes and their spacing. It may help to consider the global figure first. General marine ecology strongly suggests that it is unlikely to be less than 10%, but is not likely to be more than 50%. Where (or when) harvesting levels outside are high (or habitat damage strong), the overall quantity needed in 'no-take' to guarrantee sustainability is likely to go up.

5. System efficiency and stability depends on supportive interactions

The efficiency of a system does not depend on maximising particular benefits or features, but on optimising the total benefits and whatever arrangements that do this.

In efficient and dynamically-stable systems, the processes interact in such a way as to provide mutual support and/or stability.

In this case, the ‘principles’ listed are *not* independent, and ‘maximising’ any one of them is *not* efficient. The principles do have multiple interactions that are mutually supportive of the overall aims.

COMMENTS ON THE PRINCIPLES

Coping with ignorance

Having observed the great increases in our marine understanding over the past 40 years, I am still far more impressed by our ignorance than our knowledge. At every level, from species description, through basic processes to interactions in ecosystems, our knowledge is insufficient to predict most natural events. The idea of positive control over these events is in the distant future. At present, the best we can do is to control our activities in the sea so that it will continue to 'manage itself'.

One way of assessing our level of knowledge is to note that the rate of discovery shows no signs of slackening. Species description, even in well-studied groups, continues at a high rate. The number of fish species known in the New Zealand region increased from ~350 in 1960 to 1000+ in 1990. For poorly-studied groups and/or regions (ie. most of both), it is hard to get order of magnitude estimates for marine biodiversity (Norse, 1993)

The same story applies to basic processes. Most of the smaller phytoplankton (contributing ~50% of primary productivity) were unknown 40 years ago, and their level of production is still unknown in many regions. For complex interactions at the ecosystem level, even 'keystone' species effects, we are still dependent on a few examples (e.g. sea otters in E. Pacific).

But this kind of factual ignorance is only part of the story. Even in well-understood features, there is little chance of accurate prediction and positive action. Sea temperatures have been studied for over 100 years, and many biological effects have been detailed. However recent El Nino events were unprecedented in this century for amplitude and duration. Their biological effects, mainly via sea temperature variations, were multiple, major and widespread. These are still the subject of active research. When, or even if, these events will be repeated is unknown.

Finally a point made by Ludwig et al (1993) needs stressing. If, even *after* the events, it is not possible to achieve a scientific concensus on the causes of major fishing collapses, it is unreasonable to suppose that our powers of *prediction* are adequate.

Those given defined tasks have to do the best they can with existing information, but it is not sensible to rely on this in general terms when the available knowledge is demonstrably still at a low level. General policy in the sea must allow for all reasonable possibilities and not just work from best estimates.

System design

Consideration of effective and efficient *systems* of 'no-take' marine reserves requires us to rethink our objectives.The present approach to efficiency is detailed, specific and analytical. It uses detailed data to define the problems as precisely as possible, to understand the processes affecting a species, and to calculate ways of making reducing problems. This approach may be appropriate for single reserves with limited objectives, but is not suitable for systems. The major purpose of systems is to protect us, and the natural ecosystems, from detrimental consequences of our ignorance and mistakes and to buffer the effects of rare, sudden, complex or otherwise unpredictable events.

By, definition, the effectiveness of such systems cannot be based on detailed information or precise calculation. 'Efficiency' in whole systems must not only allow for lack of precise knowledge, but also assume that detailed objectives are unknown or ill-defined. 'Effectiveness' of systems does not depend on getting the parts tuned to a particular effect, but on ensuring that the overall design will cope with unpredictable mistakes, rare events, and unperceived complexities.

There are plenty of effective and efficient systems (both natural and human - designed), where we can observe and copy the basic management and design crieria required. The only problem is that, in well-established systems, most of the actual discussion and day-to-day action is about detail. Precisely because they do work effectively in general terms, the basic principles normally receive little attention.

Whether we are *designing* road networks, school systems, or the organisation of fire brigades, or just *observing* blood systems in an individual, dispersal mechanisms in a species, or maintenance processes in an ecosystem, the same basic principles are repeated.

When designing systems, details must be ignored.

A road-network planner must not waste time or energy thinking about who will travel, where or when they will travel, by what route or for what purpose. The plan must maximise the possibilities for travel. It must provide alternative routes and allow for purposes not yet conceived. Nor should the *net-work* designer worry about which pieces will be constructed *first*, or why. The overall efficiency of the network will not depend on these details, indeed it will be seriously reduced if these are given much attention at the design stage.

Natural constraints are paramount.

This priniciple follows from the first. The basic criteria for the design of a system are not related what we now know about purposes (human needs and desires, which will certainly change), but to the natural constraints (most of which are permanent). For a road network, the topography, rivers, and coasts are permanent constraints, the present industries and population centres are not.

SOCIO-POLITICAL PRINCIPLES

The views of the general public and their elected representatives, who will actually make the decisions on any marine reserve systems, are critically important. It is easy to be complacent or cynical about the public's capacity to understand technical issues, it is wise to test this before basing any policy on it.

Over the past 30 years I have spoken on marine reserves to a large number of public meetings, schools, and other groups, including elected politicians. This experience covers several countries, many different regions. and a wide range of initial hostility/support. I have found that the great majority of people (even when they have only thought about the matter briefly) do believe the following points:

Representation:

(a) Different pieces of the sea (regions and habitats) have different animals and plants.
(b) We do not know all the species, still less what they all do.
(c) Keeping examples of all (and their habitats), until we do know, is common sense.
(d) Setting *theoretical* priorities for doing this is silly. It is like trying to rate the priority of parts of your own body - i.e. pointless unless you are forced to do so, and then pointless because it will happen anyway.

Replication

(a) Most knowledge depends on having more than one instance.
(b) For important things, we need separate examples, in case of accidents or mistakes.
(c) If 'undisturbed' examples of some habitats are popular for education, recreation or any other common use, then we need more of them.

Network

(a) Covering all the options is better than picking one, especially if we know very little.
(b) The dispersal and migrations of different species will be different.
(c) Currents are likely to vary a lot between years.
(d) A system should maximise the benefits by multiplying the possibilities. It should not calculate the theoretically 'best' arrangement and just have that one.

Amount

(a) The area where fishing is allowed is less important than the state of the fish stocks.
(b) Banning fishing in 20% of the area of a stock is likely to be helpful in the long run.
(c) Fishing and mining are not the only uses of the sea or the most important ones - merely those that are easiest to argue about.
(d) The really important functions of the sea - like control of the world climate - are only dimly recognised and far from understood.
(e) A 'no-take' marine reserve system must be able to sustain itself, and should aim at sustaining all the functions of the sea.

In short, the general public (even when unaware of detailed evidence or unable to put their views into words without help) is well up on the basic principles. They may even be ahead if the 'experts' are deep in detail and not thinking about general principles.

The fact that most people would agree with all the principles does not prevent them from arguing fiercely against any particular proposal that might cause them some inconvenience. This is the so-called 'NIMBY' principle (from 'Not In My BackYard). However, NIMBY is not a real obstacle when we decide to act on principle.

If a town does not have a school, it will soon get one when the general public and high-level politicans learn this fact. This will not depend on finding a school site welcomed by those living close by. On the contrary, we know that, whatever site is selected, some of those nearby will complain bitterly and do all they can to stop it. Many of their complaints will be real and, from their viewpoint, justified. But this is unlikely to hold things up, because the general public (and their elected representatives) feel that, *in principle*, the education of all children is more important than the convenience of some citizens.

When marine reserves are approached in principle, similar events will follow. NIMBY will not disappear, or even reduce much, but it will cease to be regarded as *the* important fact or even a significant impediment. Scientists who wish to advance 'no-take' marine reserves must help to shift the discussion to the level of principle.
The public can and will support this, but they are usually unable to act alone. Not only do they find it difficult to express their feelings in suitable words, they are unwilling to face up to 'experts' (hired by fishing or other interests) who can baffle them with jargon, detailed data and highly-selected pieces of genuine science.

The politicians are generally in the same boat. If they are going to come out in principle for 'no-take' marine reserves, they need protection from those who feel (correctly or not) that their interests are threatened. They need scientists to spell out the principles; to discuss these both in scientific format and in terms accessible to the lay public; to explain what general benefits are likely to acrue from acting on the principles; and how this might operate.

At present, most marine scientists are directly employed to look at particular problems, or have chosen to investigate detailed phenomena. It will not be easy to alter this, but we could reasonably aim for an upgrade in professionalism to include open public support for sensible general principles.

HOW TO APPLY THE PRINCIPLES - EXAMPLES FROM NEW ZEALAND

The aim of this section is to show that scientific principles can help in practise. In particular the examples show:
(a) Available information (even when quite sketchy) is sufficient to make recommendations which are scientifically-sound and politically-useful.

(b) The precise location and absolute size of any particular marine reserve is not strictly a scientific question if the aim is to create a representative and self-sustaining network of such reserves. Scientific principles do provide real constraints on sizes and location, but there are usually several, if not many, alternatives that match these constraints.

Biogeographic representation

The marine biogeography of New Zealand is relatively simple, but includes examples of most major aspects and so provides a useful model in which to discuss the application of biogeographic principles. Heath (1993) reviews the physical oceanography and Walls (1995) reviews the marine biogeography of inshore seas.

(a) Major climatic distinctions (due to primarily to latitude).
The New Zealand region spans ~30 degrees of latitude and the range of climate is considerable. The *Kermadec* Island group and its associated waters are ~ 1000 km nort-east of the main islands and are clearly distinct in basic climate terms. The fauna includes many tropical genera not found elsewhere in the region. (

(b) Major oceanic currents, convergences and fronts.
The *Sub-antarctic Islands* and their associated plateaux lie south of the Subtropical Convergence in different water masses to the rest of the region. The fauna there has many genera in common with Antarctica and other circumpolar islands like Kerguelen.

(c) Simple isolation.
The *Chatham Islands*, although on the same latitude as the South Island of New Zealand are separated from it by ~750 km of water more than 200m deep. The benthic biota of the Chathams lacks many species found around South Island, and those that it shares are apparently a 'chance set' that have somehow managed to cross the gap.

d) Regional currents, up-wellings, and associated features
The W*est Coast* of the main islands of New Zealand are strongly affected by the prevailing West to South-west winds. Wave action is strong and persistant, as are induced coastal currents. Local upwelling and high productivity are common.

(f) Extensive coasts may develop significant clinal variation
The *East Coast* of the main islands is affected by warm currents in the north, cool currents in the south and complex mixing in the centre. Few species are equally abundant along this north/south cline and most only occur over a portion. In clinal variation, the number and boundaries of *any* sub-divisions are arbitrary. However, if the cline is important, 3 divisions are the *minimum* for 'representation.'

(g) Interactions and borderline cases
Several other areas around the main islands have claims to biogeographic distinction. Three of these have complex and highly-variable hydrographic features - the far north, Cook Strait and the extreme south (Ballantine, 1993). Others are have very distinctive topography - e.g. Fiordland and the Marlborough Sounds. One, the shallow waters round the string of islands along the north-east coast is characterised by both. In all cases, however, it is a matter of opinion whether these features and their biota are sufficiently distinct to warrant *biogeographic* distinction. But even if denied

biogeographic distinction, these areas would clearly require 'representation' as major ecological variations.

Even a highly conservative view of New Zealand marine biogeography shows that there are **three offshore island areas** with distinct water masses, marine climates and biota. Around the main islands there are, at least, **four coastal marine areas** with major differences in their physical regimes, fauna and flora. All seven biogeographic regions need representation in a marine reserve system.
Three or more further distinctions are possible -
(a) in the north, around the Three Kings Islands and tip of North Is.
(b) in Cook Strait, including the Marlborough Sounds
(c) in the south, including Fiordland, and around Stewart Is and the Snares.

Ecological representation

In the open ocean, major ecological distinctions are largely a matter of water masses and depth in the water column. In shelf waters, depth is still important but there is an added complexity due the shape of the coast and the associated topography. Separating at least four ecological inshore/offshore zones related to coastal topography and depth is highly conservative :

Enclosed harbours and estuaries
Sheltered areas on indented coasts
Open coasts and the inshore shelf
Outer shelf and any offshore islands

A minimum ecological representation of any region would require an example of each of these (if they occur - there are no enclosed or sheltered areas at the Kermadecs Is). All the ‘border-line biogeographic’ cases, given above, would be prime candidates for ‘ecological represention’ in their regions.

Ecology, replication, network design and total amount

On straight coasts, with more-or-less parallel depth contours, representation is generally achieved by having reserves as ‘stripes’ normal to the coast. Arranging replication, ‘network’ and the appropriate total is largely a matter of adjusting the width of the stripes and their spacing. However, even in this relatively simple case, it is important to note that:
(1) Some questions may not have a **single** answer. *What is the best width and spacing for the reserves?* Even when data is available, this question is likely to have different answers depending on the species considered. So we should consider including some variety.
(2) The answers to some questions may require optimisation of several principles. Even on relatively straight coasts, the spatial variation of inshore habitats is likely to be greater than off-shore. Human activity is likely to be more varied and more intense close to shore. The ability to define a boat’s precise position declines off-shore. The *combination* of these points suggests that inshore reserves should be smaller and closer compared to off-shore ones.

The Greater Hauraki Gulf (on the NE coast of North Island) is chosen to provide detailed examples. This area (which comprises about 40% of one biogeographic region) has a complex coastline and topography (high fractal morphology). It is the most 'advanced' in terms of marine reserves - 8 established already and at least 8 more in an advanced stage of public discussion. It is the most populous area of New Zealand - the Auckland metropolitan area has over 1 million.

1. Ecological classification

A division into 4 grossly different ecological areas based on simple physical features is given. Most ecologists for most purposes would want more and finer distinctions, but this degree of differentiation is easy to understand and would be acceptable by virtually anyone.

(a) Harbours and estuaries - more-or-less 'enclosed' and very sheltered.
(b) Sheltered waters - less than 50m deep and protected from most swell.
(c) The Inner Shelf (less than 75m depth) on open coasts
(d) The Outer Shelf on open coasts and the open sea.

2. The development of a marine reserve network has three stages:

a. The creation of some reserves promoted by a variey of special and local reasons. This stage is now complete in the Hauraki Gulf.
b. Pressure for more reserves to 'fill the gaps' in representation, and to create replicates for the more 'popular' habitats. This stage is in progress.
c. Agreement to proceed on principle and complete the network. This stage not yet started, but there is already strong support for it in some quarters.

3. Size and spacing

The ecological argument for increasing reserve size and distance apart when moving inshore to offshore, especially where the coastline has a high fractal, is fairly obvious in this region, but has not be reflected much in reserve creation so far.

4. The develoment of network connections

The increase in 'network connections' (inter-site distances less than a specified amount) as more reserves are created is surprisingly great - but is simply demonstrated on a map. In this area (provided the principles are used):

	Number of Inter-site distances	
Number of reserves	< 30 km	30-50 km
8	2	2
16	8	8
24	22	36

Given a network design, it is not necessary to predict or arrange for actual larval transport routes (or similar phenomena). This is important since different species will have different 'requirements'. Only a system providing a very wide range of 'pathways' will cover the necessary range.

5. Scientific principles and precise selection of reserve sites
As the number of established marine reserves increases, the scientific principles increasingly constrain the 'remaining' choices. However it is important to recognise that this is merely a matter of probability - it does not mean that *any* was required for the network. Given a different starting point (i.e. the initial reserves in different places) completely different networks (none of the same sites) can be constructed using the same principles and achieving the same effects. One example is shown.

CONCLUSIONS

The creation of 'no-take' marine reserves is a political process. In a democarcy, the decisions will be based on the opinions of the general public and their elected representatives. Scientists, should not, and will not make these decisions. However, politics is not in full control. The actual features of the natural world (physical and biological) will constrain what can be done, and control the effects of what is done. Just because large numbers of people want something to happen, and believe it will happen, has no effect at all in the natural world.

Science can help produce more sensible descisions in many ways, but only if scientists (and politicians) are clear about the boundary between politics and science. At present, in the matter of 'no-take' marine reserves, this destinction is extremely confused. If scientists, especially fisheries scientists and marine ecologists, put more effort into what is genuinely their business and stop meddling with matters that are properly political, the entire situation would dramatically improve.

Scientist should concentrate on the necessary principles. Even with existing data it is likely these could be developed usefully - we have hardly started this process. They should work on the large natural constraints in their regions, the main physical characteristics (topography, water masses and currents), large-scale biological features (biogeographic and ecological) and the interactions of these. It is likely that the general picture of representation, reasonable levels of representation, and sensible types of network will be fairly obvious, once we look for them. They should learn to express the scientific principles, the constraints and their consequences in terms that are clear to the general public, their elected representatives and the appointed managers.

1. There are already enough examples of 'no-take' marine reserves to show they are practical in socio- political terms and provide a wide range of benefits.

2. The benefits include
(a) direct benefits - to scientific research, education at all levels, many forms of recreation, provision of information to management, monitoring natural marine variation and the conservation of marine diversity (genetic, species and habitat).
(b) indirect benefits - by providing marine ecosystem support and general insurance against unpredicable or unpreventable events, especially for harvested species.

3. These benefits would be optimised if 'no-take' systems had the following principles:

(a) representation (of all biogeographic regions and all ecological habitats in these)
(b) replication (several separate examples of each representation)
(c) network design (maximising the pathways for recruitment and other support)
(d) a total amount sufficient for the system to be self-sustainable.

4. The total amount (by area) required to provide for the direct benefits would need to be at least 10%, the total amount to optimise the indirect benefits would be ~ 20-30%.

5. Moving to *systems* of marine reserves, and applying the above principles in the order stated, avoids most of the scientific problems that arise in 'one-by-one' or problem-solving approaches. Detailed predictions of effects are no longer expected and difficult cases at each level (biogeographic, ecological, replication, network) can be treated as simple decisions at the next level.

6. Accepting the principle of representation removes any scientific need to place regions or habitats in an order of priority. The principles of representation, replication and network design mean there is no scientific need to precisely locate the sites, nor for detailed survey data to achieve this.

7. Provided that the principles are adhered to, it is scientifically permissable for socio-political reasons to be used to develop the detailed priorities and precise locations of actual 'no-take' reserves in the system.

8. Moving to multi-purpose *systems* of marine reserves (and accepting the principles) avoids most of the political problems that are serious at present when each reserve is considered separately. The general public will give active support to sensible systems, whereas local proposals attract little attention except from those adversely affected.

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