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Perspective

Fifty years on: Lessons from marine reserves in New Zealand and principles for a worldwide network

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ABSTRACT

New Zealand pioneered marine reserves, areas in the sea protected from all direct human interference. The first reserve was proposed in 1965 and established in 1977. It has operated successfully ever since. Even one instance proves that such things are possible.

All marine reserves in NZ were initially greeted by a range of objections, and widespread and often loud opposition, This is not surprising since marine reserves prohibit many existing activities and seriously challenge many general opinions. Such opposition is to be expected.

Successful establishment of marine reserves in the first stage was only possible when the proponents were very persistent and had community support. It helped if they could take advantage of some special local circumstance e.g. an adjacent marine laboratory (Leigh), spectacular underwater scenery (Poor Knights), unique biogeography (Kermadecs), cultural significance (Mayor Island), or severe fishery problems (Long Bay).

Careful examination of the objections to marine reserves showed that they were mostly based on misconceptions or misinformation, and can be successfully countered in the public mind by answers based on common sense arguments or well-established facts. Developing these answers, and testing them in the public arena, proved surprisingly useful in both scientific theory and practical politics.

When marine reserves were established, their ecology began to change, due to the cessation of fishing and other previous manipulations. These changes were complex, often large and continued to develop for decades. The study of these changes, and a continuing comparison to fished areas provided a great deal of new scientific data showing how fishing directly and indirectly alters ecosystems.

The scientific benefits of marine reserves proved so numerous that it became clear that marine reserves are as important to science as clean apparatus is to chemistry, and for the same reason. They are the controls for the uncontrolled experiment that is happening due to fishing and other human activities.

The general benefits of marine reserves to society as a whole; directly to conservation, education, recreation and management, and indirectly to fisheries, tourism and coastal planning; are so important that a systematic approach to their creation is in the public interest.

The experience with existing marine reserves (35 to date) is sufficient to state the principles needed for such systems: representation and Replication (of habitats and species); a geographically widespread network; and a total area sufficient to be self-sustaining.

Most of the lessons from New Zealand are based on fundamental human and ecological factors and would be applicable world-wide. Other regions could by-pass the long struggle that occurred in New Zealand and move directly to creating marine reserve network systems based on our experiences and these principles. This has already started to happen in Australia and the USA.

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1. Introduction

This paper reviews 50 years of experience with marine reserves in New Zealand and attempts to extract from this the principles necessary for their successful establishment. Progress in New Zealand was slow, but continuous (Fig. 1). There are now 35 reserves, more are planned and the idea has considerable support with the general public, politicians, scientists, teachers and conservation interests (Fig. 2) (Enderby and Enderby 2006). Attempts are under way to create a full system of marine reserves.

New Zealand pioneered marine reserves. In 1965, the idea of a marine reserve adjacent to the Leigh Marine Laboratory was raised at its management committee meeting. The laboratory had been established in 1962 by the University of Auckland on a cliff-top 100 km north of the main campus (reference). It was in its infancy, just one room and one staff member (myself!). At the meeting, the chairman, Professor V.J. Chapman said 'We must get a marine reserve!' The rest of us just looked blank. 'You know', he said, 'a protected area where they can't eat our experimental animals or kick our apparatus to bits'. 'Good idea' we said, so he wrote to the government. Their reply was that no legislation existed to do such things and they were very busy with other matters - the polite bureaucratic equivalent of 'Get lost'. But Chapman had not become a world expert on marine algae, salt marshes and mangroves (e.g. Chapman, 1957, 1974, 1976) by sitting about, so he started a campaign for an Act of Parliament that would allow such things. He wrote every month for years with new arguments and data. As he said, 'The chosen weapon of bureaucrats is paper, if you want to challenge them you have to build a file; if you want to win it has to be big file.' He got formal support from the New Zealand Marine Sciences Society (Hickman, 2010) and the NZ Underwater Association (recreational divers). We organised public meetings, lobbied politicians, gave school talks and generally made a nuisance. After six years, the then Marine Department produced a Marine Reserves Bill and passed it through Parliament as the Marine Reserves Act (New Zealand Government, 1971). Four years later in 1975 our application for a reserve was accepted by the New Zealand government, and after only another two years the paper work was done and the first fully-protected marine reserve in New Zealand, perhaps the first in the world, was officially opened by the Minister of Fisheries (Ballantine and Gordon, 1979; Ballantine, 1991,1995,1999; Hickman, 2010) (Fig. 3). It was formally titled the Cape Rodney to Orakei Point Marine reserve, but is commonly called the Leigh or Goat Island Marine Reserve.

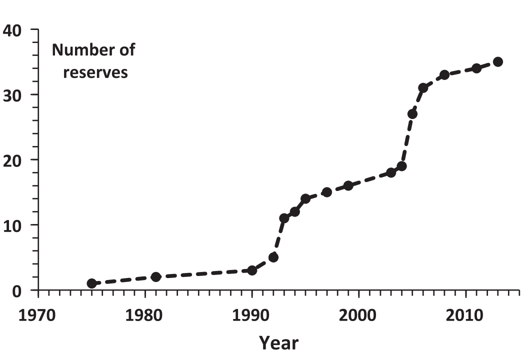

Fig. 1. The growth of Marine Reserves in New Zealand.

The history of marine reserves in New Zealand has been long and complex. Indeed, it is most succinctly described as messy. There was rarely any clear policy and various agencies had different agendas. Many of the twists and turns are described in Ballantine (1991), but the details are mostly of local or historical interest. Nevertheless, progress has continued for more than four decades. There are now 35 reserves, with at least 8 more in the pipeline (Department of Conservation, 2013). Established reserves cover a wide latitudinal range, from the Kermadec Islands in the sub-tropical north to Auckland Island in the sub-Antarctic. Reserves now occur in all regions within the country, and examples cover a wide range of habitats from estuaries, harbours and fiords, all types of open coast and around off-shore islands. Many reserves are remote from population centres (e.g. Kermadec Islands) but some are within the city of Auckland, a city of 1 million people (e.g. Long Bay, Pollen Island).

1.1. What are marine reserves?

There are real problems with nomenclature. In different parts of the world the same words (marine park, reserve, sanctuary, etc.) are used to mean totally different things. In the USA, a Marine Sanctuary can permit almost any activity except drilling for oil, whereas in Australia Sanctuary Zones are strictly no-take areas within large multi-purpose Marine Parks. The label Marine Protected Area and its acronym (MPA) are now in common use, especially by those attempting to plan and manage the sea (Claudet, 2011; Mulcahy et al., 2012). However, the definition of an MPA is so broad and vague the term has little value. Indeed the use of this

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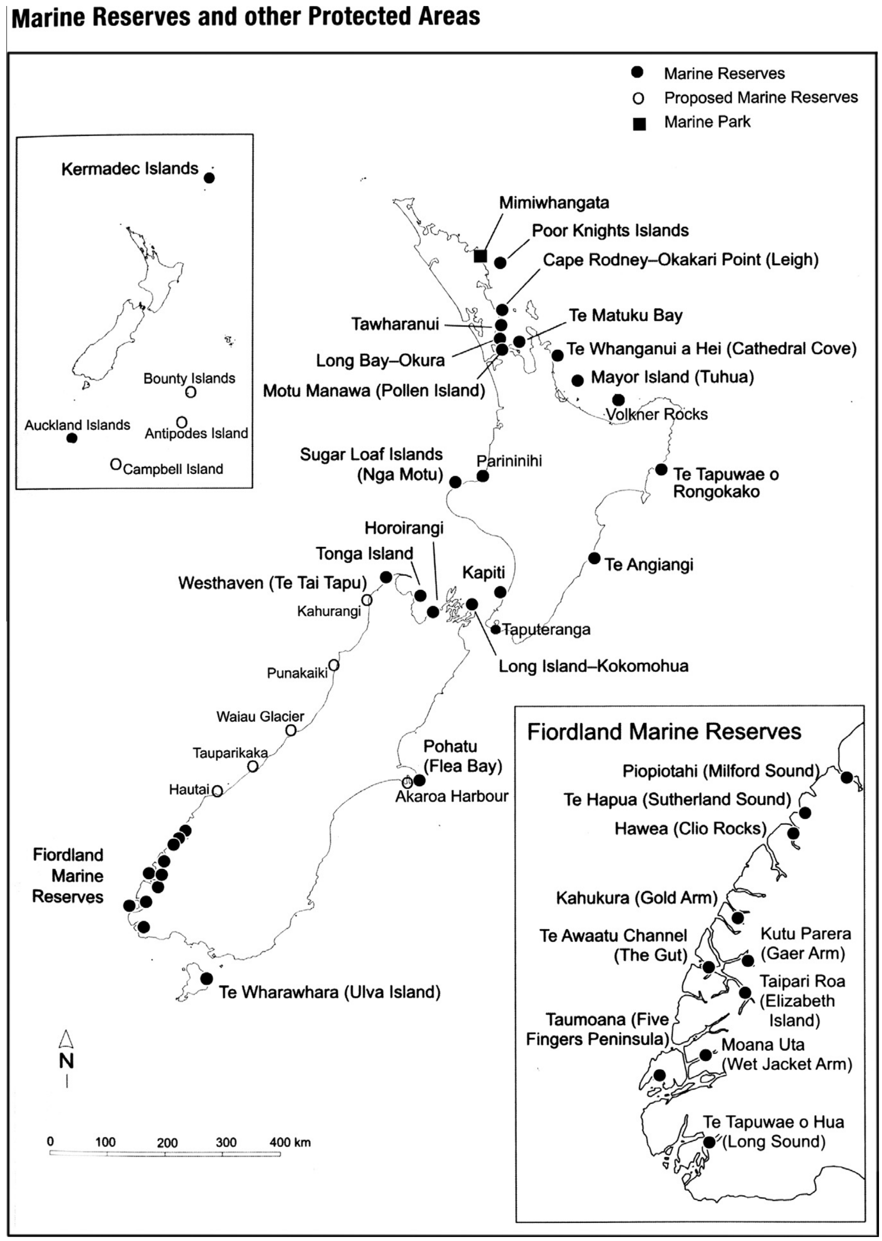

Fig. 2. Locations of actual and proposed Marine Reserves, and Marine Parks, of New Zealand.

label merely adds confusion to the situation. Almost any piece of sea that has one or more special rules can be called an MPA (e.g. submarine cable zones). This makes the label attractive to politicians and government agencies because they can say they already have some MPAs and are planning more. They can then imagine they are dealing with the problems of marine planning and management. However, this is like saying if we have some buildings called schools we are dealing with the problems of education! Most MPAs protect very little and many are 'just paper parks'. In this paper, Marine Reserves are defined as permanently 'no-take' areas in the sea where human disturbance to species and habitats is minimised.

In sharp contrast to the vague idea of MPAs, New Zealand and a few other countries (including USA and Australia), have developed this concept of marine reserves where no disturbance is allowed (Roberts et al., 1995; Edgar and Barrett 1999; Johnson et al., 1999; McCook et al., 2010). This idea was new, different and additional to existing methods of marine planning. While the idea is simple it is so different from existing practise that experienced managers find it difficult. They find it hard to see how 'no-take' marine reserves fit into existing zoning systems, protocols and methods. They are correct because marine reserves are additions to such systems. Unless this is understood and accepted we will be distracted by endless misconceptions. The necessary rules for Marine Reserves are:

- No fishing of any kind.
- No removal of material, living, dead or mineral.
- No dredging, dumping, construction or any other activity that would disturb natural processes.
- Subject to the above, the encouragement of people to view, appreciate, study and publicise the results of this protection.
- These rules and the reserves are permanent.

The essential regulations for marine reserves are those needed to maintain the full expression of the intrinsic processes in the

Fig. 3. An underwater and overwater view of the first Marine Reserve in New Zealand, at Goat Island, Leigh.

sea and hence allow the free development of natural biodiversity at all levels. At first sight these rules seem extreme and initially many people thought they were unnecessarily so. However, when 'weaker' versions were tried, it became clear the firm versions were essential for both scientific and practical reasons (Willis et al., 2003; Denny and Babcock, 2004).

Marine reserves are:

Proactive and are applied on principle; rather than reactive and applied to a problem. There is no need to identify each potential problem, nor to wait for problems to occur. There is no requirement to show that a particular disturbance causes any given level of damage. Marine reserves are kept free of all direct extractive or other disturbances on principle. No-take marine reserves' status cannot confer protection from more generic effects such as sedimentation, pollution and climate change; these require mitigation on catchment, regional or global scales.

Additional to existing systems of planning and management. Detailed, data-dependent, problem-solving management will continue to operate outside marine reserves. General marine planning (e.g. zoning) will also continue and develop. Marine reserves are additional to these methods. Most of the sea will still be managed with a focus on active human uses, their problems and conflicts, but marine reserves will provide areas where no direct extraction or engineering operates.

Supportive of standard planning and management systems. Standard management requires good data, appropriate analysis, social awareness and political acuity, as well as practical and economic methods to remove or reduce any problems. None of these features can be guaranteed, especially the first. Marine reserves provide buffers and insurance against the effects of management 'error' from whatever cause. Marine reserves act to maintain natural biodiversity and processes independently of other management (e.g. fisheries).

Necessary for effective marine management. There are many reasons why standard management needs the kind of support that marine reserves can supply. For example (i) Our existing knowledge of marine life and its natural processes is not complete. Major discoveries continue apace, proving there is still much to learn (e.g. Appeltans et al., 2012; Costello et al., 2013a,b,c). While we must act on the information to hand, it is not reasonable to rely on it being adequate to cover all purposes. (ii) Our technological power continues to increase, so each year there are fewer 'natural' refuges from our exploitation. (iii) Human numbers also increase, so the intensity of exploitation increases. It is necessary to arrange marine reserves to insure against ignorance, provide natural refuges, mitigate the increasing pressures and ensure that the intrinsic ecological processes in the sea are maintained somewhere. (iv) Marine reserves cannot be completely free of human impacts but are areas where their direct impacts are eliminated or minimised. These areas provide one of the greatest potential benefits to conservation and fisheries generally because they allow the effects of fisheries extractions and conservation actions to be clearly differentiated from more generic factors influencing marine populations such as pollution and climate change. Indeed, only with marine reserves will it be possible to distinguish the local effects of climate change from fisheries.

1.2. Marine reserves can work anywhere

The concept of marine reserves is quite different to standard marine management. It is proactive rather than reactive. Its operation does not depend on detailed information. Marine reserves are additional to detailed and general marine planning and management which will continue to operate outside the reserves. Marine reserves give essential support to these management systems, by providing insurance and buffers against ignorance and errors. In particular they act as 'control' areas that help distinguish between generic and local direct human impacts on marine ecosystems. The knowledge of the more natural (baseline) state of ecosystems can only be observed using marine reserves as the 'controls'. This may be their greatest benefit to science and natural resource management.

The known benefits of marine reserves form a long and varied list. More benefits are continually being discovered. Many direct benefits to science, education, conservation and various forms of recreation are now well-established. Indirect benefits to fishing, tourism, resource planning and ecosystem health are steadily becoming clearer from empirical data and from modelling. The potential benefits of marine reserves are universal in scientific and social terms. They are independent of bio-geographical region and ecological habitat, and also of culture, politics and economics. Marine reserves can work anywhere.

Since marine reserves provide a wide range of benefits, it would be sensible to arrange systems (i.e. networks) of reserves that would optimise these benefits. No country has yet done so, but several including New Zealand and Australia have plans in that direction. The principles for such a system are reasonably clear. Representation, Replication, Network Design and a Total Area sufficient to be self-sustaining. All regions would be represented in the reserve system and, within each region, all major habitats would be represented. For many reasons, several spatially-separated examples (of each habitat) would be required in each region (Replication). A Network Design would be required so that the decoupling of recruitment from reproduction in most marine populations by the planktonic dispersal of eggs and larvae is used to sustain the system. The total area of the system would need to be sufficient to make the system permanently self-sustaining. This paper will describe these features of marine reserves and my experience in campaigning for them.

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2. Lessons from objections

Whenever a marine reserve was proposed there was generally a chorus of opposition and objection. The New Zealand Marine Reserve Act requires the proposer of the reserve to consider and reply to all of these before a final decision is made. Fortunately, the same arguments for objection keep recurring and so 'answers' can be developed and practised. The commonest objections are listed below.

2.1. People are part of nature, everything they do is natural, including fishing

This argument is logical but it is merely semantic. If we choose to define 'natural' in this way then we need other ways to describe what fish and habitats do in the absence of exploitation by people. Whether fishing is natural or not, it has significant effects not only for fishermen, but also on the fish and their habitats. This is even more obvious for dredging, dumping, and reclamation. Marine life and habitats have their own intrinsic dynamics which will operate in the complete absence of people. While we can, and often do, affect these dynamics by our actions (e.g. by fishing), we need words for the independent 'natural' dynamics. If some people do not wish to use the term 'natural' for these, they must provide some clear alternative to cover the point. They must not be allowed to deny there is a difference caused by exploitation. If we are to have effective management in the sea we need to know the difference between what we have caused by our activities and what would have happened anyway.

2.2. What's the problem? If it ain't broken, do not fix it

At first sight this argument seems hard-headed and practical, but it includes several unreasonable assumptions. First the idea assumes there is some simple 'it' when in fact we are dealing with a very complex set of populations, habitats and ecosystems. Then the argument assumes that we would be able to recognise when and where these systems were 'broken' or damaged. It took 20 years before we realised that the sea urchin dominated habitats in New Zealand were a consequence of fishing out their predators and were not 'natural' (e.g. Leleu et al., 2012). We have not yet discovered all the species in any geographic region, including New Zealand (Gordon et al., 2010; Costello et al., 2010, 2012). We keep discovering more of the processes involved. We have no reliable way of telling whether the essential processes are operating properly, or even, in most cases, what 'properly' means. Given these levels of ignorance, it is dangerous to rely entirely on noticing when things 'are broken'. What the proponents of this argument are really saying is that if *they* have not noticed any problem or inconvenience then there is nothing wrong. They are, of course, entitled to think this, but the rest of us can recognise that this attitude is narrow-minded, short-sighted and quite inadequate for sensible management.

Despite the above 'answer', this form of argument was used in New Zealand to deny the principle of full protection for the second marine reserve (around the Poor Knights Islands) established in 1982. The authorities and many ordinary citizens felt that some kinds of fishing were doing no harm and could be allowed to continue in the 'reserve'. The Marine Reserve Act was amended to make this possible (reference). So the initial regulations permitted a short list of species to be caught by a short list of methods in 95% of the 'reserve' by recreational fishermen. All commercial fishing was prohibited. For a few years the plan seemed to be working and those in charge congratulated themselves on a victory for pragmatism. However, problems slowly emerged and steadily became more serious. Enforcement was difficult due to the complex rules. The majority of visitors, many of whom had come long distances to witness the spectacular natural life and underwater scenery were annoyed to find *any* fishing going on. Other visitors came especially *to* fish, under the impression it must be better due to the restrictions. Thus the 'MPA' status attracted fishermen (Denny and Babcock, 2004). Two conflicting groups emerged. Explanations about the rules became tedious and confused (Department of Conservation, 1995). After two rounds of public submissions, a court injunction and a great deal of political fuss, it was finally decided (after 16 years!) to make the whole reserve strictly 'no-take' with consequent rebuilding of fish biomass (Willis et al., 2003).

The lesson was painfully learnt, but was perfectly clear. If we merely wish to reduce some fishing pressure (for any reason) we should not involve the idea of marine reserves at all, simply apply some extra regulations under standard fisheries management. If, however, we want the full range of benefits a marine reserve can supply, we must have the full set of five rules stated earlier. The long and messy argument over the rules at the Poor Knights taught this lesson to New Zealanders the hard way. All subsequent marine reserves in New Zealand have been 'no-take' and undisturbed.

2.3. Universal fishing is a basic right, unless there is a clearly defined problem

This is simply mistaken. The rights of others and society as a whole must be considered. Fishing is indeed generally permitted, but can be cancelled temporarily or permanently for a wide range of reasons deemed to be in the public interest. Conservation is only one of many reasons (Table 1). We hear a great deal in the media about the 'rights' of fishermen, but the 'rights' of others are rarely mentioned. What should we think about the 'right' of children to see for themselves the full display of marine life. Is it sufficient that they should just see what the fishermen did not want or could not catch? I personally consider that it is a basic human right of all children to experience the rich range of natural life, and that we should make real efforts to arrange this. We already do on land. We keep representative pieces of forest and other habitats primarily for education, regardless of their economic value. I think we should do the same in the sea. It is relatively easy once we put our minds to it. At the Leigh Marine Reserve it is common for whole classes of children (some even of primary school age) to go snorkelling. A few years ago, some genius discovered that if you put a wet suit on a child, it not only keeps them warm, it keeps them safe. Whatever they do, they bob up like corks.

2.4. Reserves should be open to fishing on rotation

This idea confuses different aims and methods. If it is helpful to arrange rotational fishing for some stocks, this can be carried out under normal fisheries management. It is not necessary to involve

Table 1
Common reasons for prohibiting fishing and/or normal access.

	Examples
Defence areas	Sensitive frontiers, firing ranges, naval bases, minefields
Dumping grounds	Munitions, poisons, radio-active material, sewage
Areas dangerous to the public	Rocket testing sites, pipelines, submarine power or communication cables, off-shore loading facilities, off-shore wind power farms
Ports and harbours	Wharves & docks, turn-around areas, mooring spaces
Shipping lanes	Port approaches, narrow straits and channels
Littoral industries	Oil refineries, power stations, ship-building yards.
Aquaculture	Shell fish or seaweed racks, rafts or lines, fish cages

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marine reserves. Indeed, it would not normally be practical. The appropriate rotation intervals are likely to be different for different species of shellfish and fish so no single cycle of opening and closure is sensible. In any case, most benefits from marine reserves, including benefits to fishing (such as developing high quality breeding stocks) increase over time, so there is no point in cutting them off at intervals.

2.5. Protection must be absolute, so people must be excluded from marine reserves

This argument while having some surface logic, is neither sensible nor practical. It concentrates on temporary and relatively trivial matters while ignoring the major driving processes. It is true that some early reserves became so popular there were problems but these were trivial compared to fishing, dredging and dumping. In any case, if marine reserves prove highly popular, it is politically easy to get more and so relieve the pressure. More fundamentally it is the activities of people that cause damage not their numbers. Marine reserves provide a *process* by which people learn to modify their activities. At first, in a marine reserve they learn that it is pleasant and instructive to have places where no one kills anything. They see more natural levels of marine life and notice how abundant these can be. Fish are unafraid and swim close to people. People thus learn about marine life like they may observe wildlife in the countryside. They better appreciate damage to the marine environment, such as overfishing and sediment in run off, and this can lead to demands for more effective restrictions (e.g. control of land drainage). Moreover, this awareness and understanding depends on their experiences in the reserve.

2.6. Marine reserves must make allowance for displaced fishing

By being no-take, reserves shift or displace fishing effort to adjacent areas. This is a classic example of an 'invented problem'. First it assumes that fishing is a fixed and definable quantity. Then it assumes their displacement could be predicted, as well as the potential 'problems' this might cause. Finally it wants some arrangement to remove or mitigate them.

In the real world, fisheries are highly dynamic. They 'displace' all the time for a wide variety of reasons (e.g. market forces and fashions, fuel costs, tax and subsidy arrangements). Fishermen are intelligent, energetic and adaptive. Most of their adjustments and displacements are not even recorded, still less monitored or measured. It is absurd to suggest these could be predicted or allowed for in any particular situation. In any case, marine reserves will cause the 'displacement' of many human activities, including coastal development, tourist destinations, outdoor education and many forms of recreation. No useful prediction or allowance can be made for them. The sensible reaction of the authorities to the idea of displaced fishing is simply to ignore it. Indeed, the fish are still there, and their progeny will disperse outside the reserve in due course to contribute to fisheries elsewhere. Even if this 'spillover' is hard to quantify and measure, it is inevitable (Ballantine, 1996).

2.7. The precise reason each marine reserve must be stated

This argument implies that the establishment of a marine reserve is the manipulative part of an experimental design. While politicians and the public can regard marine reserves as a social experiment in the simple sense of being a new and different arrangement; in scientific terms a marine reserve is a 'control', the un-manipulated part of an experimental design. This means that quite different scientific rules apply. An 'experimental manipulation' requires a reason (a hypothesis to be tested), but this is not true for a 'control'. The same 'control' can be used for any number of experimental designs, all that is required is that remains unmanipulated. By definition, marine reserves are free from all preventable disturbances, so they can act as controls for any comparisons involving human disturbance in the sea. We do not expect 'responses' from controls in an experiment. Thus 'recovery' of species populations and habitats in reserves are the result of the impacts of human activities *outside* reserves.

The marine reserve at Leigh has already been used for many comparisons (inside to outside the reserve, before and after) including the abundance, size and behaviour of various species (e.g. Shears and Babcock, 2003; Babcock et al., 1999; Leleu et al., 2012). It does not make any scientific sense to ask which of these was 'the' purpose of the reserve. This point extends to other aspects. If a reserve provides for education, for the protection of scientific equipment, and/or for natural ecosystem processes while still providing for valid (un-manipulated) scientific control, these are simply added benefits.

Most no-take reserves have an underlying purpose to keep the environment in a more natural state than adjacent areas. However, this does not mean that a particular goal or target can or should be set for the 'recovery' of biodiversity, as may be the aim of conventional monitoring. Indeed, the New Zealand experience was that many of the ecological changes would not have been predicted.

2.8. Marine reserves lock up valuable fisheries resources

This argument rests on a very simplistic view of population dynamics, and can be easily refuted by reference to farming. In New Zealand, cattle rearing for meat production is common. Over the years, the farmers realised that 'reserving' a small proportion of farms for stud bulls and using these for artificial insemination allowed better breeding. They also found that 'reserving' a significant proportion of farms for nursing cows was helpful since these cows benefit from a different pasture management than that best for growing steers to full size for the market, as occurred on most farms. The stud farms and nursery farms send little or nothing to the market, but, if you suggested to the farmers that they had 'locked up' a productive resource they would just smile and write you off as simple minded.

Marine reserves automatically and inevitably act as stud farms and nursery grounds for all the species they contain, especially those targeted outside by fishermen. Inside a reserve individuals can grow and survive to their natural limits. Larger and older individuals produce more gametes (eggs and sperm) than smaller ones not just absolutely but relatively (i.e. more per unit weight). There is also evidence that such mature fish produce larger and more viable eggs (e.g. Trippel et al., 1997). It is clearly in the interests of fishing to have a significant proportion of each stock area protected in marine reserves. Such reserves convert more of the available food to gametes and the resulting progeny are free to move into fished areas.

3. Surprises (unexpected lessons)

3.1. Public responses

When the first Marine Reserve was proposed in New Zealand the intention, as stated in the Marine Reserves Act, was to keep the area free of human interference except for the purpose of scientific research by the adjacent university laboratory. The government also assumed that because it was designated for scientific purposes, that there would be only one or two more needed reflecting the locations of other universities in the country. Contrary to expectations, the reserve became increasingly popular with the public and schools; now more than 50,000 people visit the reserve each year (personal observations based on regular counts of vehicles in car park). The reserve has become a significant tourist attraction, and is estimated to be worth several million dollars per year to the local district. Local real estate adverts often refer to the distance from the reserve. The public and government view is now that the first priority is conservation and secondly scientific research. Scientists doing research are sometimes reported by the public resulting in the warden or ranger calling down to investigate! After initial objections, some local fishermen became champions of the reserve because they can now show friends and relatives what the coast used to be like before the larger fish and lobsters were fished out, and they may notice the benefits of 'spill-over' where large fish and lobsters may be caught just outside the reserve boundary. Furthermore, there was a rise in public support and many more reserves were proposed; about half of these by local groups and half by the government.

In short nobody expected such huge public interest, nor the defensiveness people showed if they thought others were breaking the rules. Similarly, local fishermen who initially poached from the reserve found that the local fish cooperative would not buy their fish. Today, any poachers tend to be non-locals who are promptly reported by locals and members of the public, greatly helping policing of the reserve.

These surprises have been repeated to varying extents in other reserves. This extent mainly varies due to public accessibility (based on access to the seashore and distance from major urban centres). In hindsight, perhaps these surprises should have been expected because they mirror the responses of the public to reserves on land where hunters often champion the protection of wildlife, including some places where they previously hunted.

3.2. Animal behaviour

But the surprises were not only social. Animal behaviour also changed. The fish lost their fear of humans, initially encouraged by people feeding them. Feeding is now prohibited, and justified by the danger of snapper biting children's fingers (snapper can crush shellfish). But the fish still swim up and watch people closely. A video camera dropped into the reserve attracts fish. If the same camera is dropped in outside the reserve fish are slow to inspect it and stay many metres away (M.J. Costello, personal observation). This mirrors the finding in land reserves like Tiritiri Matangi Island, where birds forage within a few metres of people (personal observation). Decades on, changes are still being observed, with large fish and rock lobsters being seen in water of only a metre depth (MacDiarmid, 1991). Previously it was thought that large fish (e.g. hapuku or grouper and ling in New Zealand) and lobsters only occurred in deep water (M. Francis, personal communication). Now it appears this may be because they were fished out from shallow water. Older citizens report that when they were children they were able to catch lobsters while wading in the shallows (MacDiarmid et al., 2013).

3.3. Ecological

It was expected that the numbers and size of individual fish and lobsters would increase in the absence of fishing. This was rapidly evident in increases in lobsters and then snapper and other fish species (reviewed by Leleu et al., 2012). Today, one commonly sees people angling and lobster pots laid just outside the reserve boundary (Kelly et al., 2002, personal observations). So everybody is aware of the recovery of these species. However, the consequence of this on the ecosystem was not predicted.

Over the first two decades of the first marine reserve being established (at Leigh), one of its most common habitats began to disappear (Leleu et al., 2012). In 1976, shallow rocks covered in pink encrusting algae and grazed by sea urchin covered almost two-thirds of the shallow rocky habitat. By 2006, the habitat has been completely replaced by seaweeds, ranging from coralline turf algae to kelp. Experiments showed that as the fish and lobsters became larger that they increased predation on smaller urchins (Andrew and MacDiarmid, 1991). Large urchins may have been too big for predators, but as they died out the grazing pressure on the rocks decreased. Small urchins are still common, but hide in crevices and under rocks to evade predation. This type of 'trophic cascade' has also been found to occuring the Mediterranean, Caribbean and in North America and Australia (reviewed by Leleu et al. (2012). It is now considered a good example of a general ecological phenomenon where top predators control the abundance of grazers and thus plant growth and cover. The above ecological changes were only the first to be discovered. Many more followed: Langlois demonstrated that the large, old rock lobsters that develop in a marine reserves roam widely, well away from their reef base. Out on sandy substrates they locate, dig up, chip open and consume bivalve molluscs, even those with the largest and thickest shells (that are immune to any predators resident in the sand community). This demonstrated that marine reserve responses could act across habitats (Langlois et al., 2005, 2006). Richard Taylor (1998) investigated the benthic fauna of habitats inside and outside the reserve and found that small, highly mobile invertebrates (such as gammarid amphipods) aggregated and sheltered in macroalgae (both turfs and kelps) in such large numbers that, despite their small individual size, their productivity equaled or exceeded that of the macrofauna (sea urchins, fish and molluscs) that had previously been considered to constitute the benthos. This suggested that 'marine reserves' can increase secondary productivity (Taylor, 1998). Small fish, including the juveniles of several important species are commonly seen feeding on these tiny crustaceans so the increased productivity may extend to the tertiary level (Francis, 2012). A visiting American Ph.D. student, using stable isotope ratios, found that benthic filter-feeding invertebrates (such as mussels and oysters) which can derive food from either phytoplankton or the fine debris from kelp, used a significantly greater proportion of kelp-derived food if they were located nearer a marine reserve (Salomon et al., 2008; Shears et al., 2008). This demonstrated that marine reserve responses could extend through the wider ecosystem.

These findings and other scientific studies collectively revealed how fishing has altered ecosystems in all but the most remote places in the oceans over the past century or more (Jackson et al., 2001). But only by having marine reserves as 'controls' can the details of these impacts be recognised and understood. Science based on fished areas alone cannot determine ecosystem impacts because it lacks these 'control' sites. It needs to be realised that most ecological research in the sea has been done in ecosystems already impacted by human activities. The findings of all these studies should be re-considered to determine how they may differ in more natural conditions. The only way to test this is to repeat ecological studies in marine reserves. Despite our experience of marine reserves, responses in newly-created reserves are not predictable even in New Zealand (Langlois and Ballantine, 2005). In other countries, the only prediction that can be made is that most responses to marine reserves, whether social or ecological will include major surprises even to those most knowledgeable about the existing conditions and activities. The main lesson from New Zealand is that our existing levels of knowledge in the sea are not sufficient to make good predictions about what will happen if we stop disturbing it. The other lesson is that all changes will be scientifically interesting and many of them will be beneficial to society in educational, recreational and economic ways.

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4. Lessons for science

Marine reserves are excellent places to conduct scientific research. Not only do they give practical protection to experimental organisms and apparatus, as Professor Chapman foresaw in 1965, they also provide greater interest and support for marine research from various authorities, grant agencies, the media, and the public. These services are effectively permanent and cost free to the researchers.

It is difficult to exaggerate the range and value of the benefits (see details in Ballantine and Langlois, 2008). Even at the lowest levels, they are important. Many perfectly sound projects were not attempted because the potential investigators were (perhaps sub-consciously) worried about the possibilities of theft, vandalism, souvenir hunters, etc. In a marine reserve the scientists effectively have a security guard at their elbow, and all it costs is friendly cooperation with rangers and managers. This cooperation is mutually beneficial. The main costs of marine reserve management concern surveillance and enforcement (Rojas-Nazar, 2013). The presence of research workers or students can significantly reduce these costs. While the scientists may have detailed programmes for where and when they will go, these are unknown to potential lawbreakers and so are unpredictable. These scientists do not need to be provided with uniforms, warrant cards, salaries or logistical support, they provide for their own needs. Researchers into bird or whale behaviour are especially valuable to the authorities as these are highly trained observers and move about a lot; but even a junior student sitting on a rock measuring barnacles is an effective deterrent to most potential poachers or mischief-makers. All she needs is a mobile phone (which all field workers should have for safety reasons) and a 'hot-line' number (which the authorities should provide anyway for public relations).

The scientific benefits of marine reserves extend well beyond protection of specimens and apparatus. Marine reserves encourage theoretical developments. As already described, marine reserves are best thought of as 'controls' and since they are protected from all direct human disturbances (manipulations) each reserve can act as the control for multiple investigations. Standard experimental design (with a manipulation and a control) becomes complicated with marine reserves for three reasons: (i) Normally the scientist simply selects controls from the general area, but marine reserves require high-level political action for their establishment. (ii) Normally the scientist decides the manipulation and carries it out, but with marine reserves the manipulations are multiple (fishing etc.) and occur everywhere outside the reserve. (iii) Normally no changes are expected in the control other than those (like seasonal variation) which will also affect the manipulation. But marine reserves continue to change after protection is applied. The changes are multiple, often large, and continue to develop indefinitely (Ballantine and Langlois, 2008). These complications require careful handling, but do not prevent proper research or rigorous conclusions. On the contrary, they open up a new range of topics for research and interest; allow a whole new set of comparisons; and facilitate a major extension of marine science (Ballantine and Langlois, 2008).

Daniel Pauly has developed the idea of shifting baselines (Pauly, 1995), and with others has shown that many marine ecosystems have steadily lost so much of their species richness and biomass abundance over time that they are now only 'ghosts' of their former nature (Dayton et al., 1998; Bohnsack, 1999, 2003). The ecological changes that occur in marine reserves after full-protection has been established are the consequence of less-disturbed and hence more natural conditions. It is highly-likely that they represent a partial recovery of the previous state, before fishing became intense. In short, the changes in marine reserves can be thought of as the reverse of Pauly's shifting baselines. This makes them not only more interesting scientifically, but also much more interesting to the public, who would really like some good news in amongst all the doom and gloom about fishery collapses and habitat degradation.

The scientific benefits of marine reserves are so wide-ranging and important that a case can be made for saying they are essential to marine science, in the same sense that clean apparatus and pure reagents are essential to chemistry. Without marine reserves, it is extremely difficult to produce un-confounded statements even about common and well-studied species.

Snapper had been actively fished for more than 100 years in New Zealand, and studied by fisheries scientists for more than 50 years. However, when studied in the marine reserve at Leigh (where it had become much more abundant than outside in fished areas) it was discovered that most individuals have quite small 'home-ranges' in which they stay for months (perhaps years) at a time (Parsons et al., 2003). Similarly, studies at the Poor Knights marine reserve suggested there was an inshore-offshore annual migration of roughly half the population (Babcock et al., 2010).

5. Lessons for conservation

5.1. Fisheries

It has become apparent from experience in New Zealand that until marine conservation is separated from 'resource management' progress will remain very slow. In theory, there are many 'marine resources' and a large range of agencies to take care of them, but in practise the overwhelming focus is on fisheries. This is especially unfortunate for marine reserves because some fisheries managers and scientists have been opposed to marine reserves. Why is this? Could it be a 'turf war'? Fisheries often consider that they are in charge of all marine life and talk expansively about ecosystem management; so they react fiercely and defensively against any 'outsiders' treading on 'their' patch, especially when the alternative approach is not to 'manage' the biodiversity but to leave it alone. In reality, fisheries spend almost all their time on the few species of marine life that have economic value. Another reason may be that the idea of marine reserves is contrary to active management which is their profession. They spend all their time collecting precise data about fish stocks and carefully calculating stock assessment models so they can recommend sustainable quotas. The idea that we should just leave some places alone, for no precisely calculated reason, seems contrary to 'management'. Whatever the reasons, the fishery authorities use every possible argument to delay or block marine reserves. At the recent Forum to decide protections around the sub-Antarctic islands, fisheries would only back half of Campbell Island waters for a marine reserve, because, they said, a crab fishery *might* develop there in the future (NZ Government, 2013).

The story of fisheries management, world-wide and over a long period, is a very sad one (Ludwig et al., 1993; Hilbron, 1998; Pauly et al., 1998; Roberts, 2007; Longhurst, 2010). Serial depletion is the recurring theme. First in particular stocks, then for whole species and habitats, and finally even entire regions. The recent history of fisheries management in New Zealand, despite the undoubted improvements due to quota management, is still far from satisfactory. There are plenty of valid excuses, and I do not suppose for a moment that I could do better with the prevailing paradigm of attempting to predict fish dynamics and then control fishing to maintain stocks. Failures in this method are not due simply to inadequate data or faulty calculation. The method is fundamentally unsound. In other disciplines (including physics and engineering) it is now generally accepted that complex systems have basically chaotic dynamics where despite being entirely deterministic and non-random the dynamics are not predicable beyond a very short time-frame, because of extreme sensitivity to initial conditions. Fishery populations have all the hallmarks of complex systems (including multiple processes and feedbacks) and hence are almost certain to have intrinsic and unpredictable dynamics. If this is so, then efforts to significantly improve stock assessment models are doomed to failure. What we need is not more data, better calculations and more micro-management, but some basic buffer and insurance inserted into the system so that it can cope with our activities. Such as a significant proportion of no-take marine reserves that would allow the resumption of more natural dynamics (which did sustain all species before we came along).

5.2. Public education

Bird watching is a recognised and respectable hobby. Adult bird watchers equipped with expensive binoculars and telephoto-lenses go to publicly-arranged reserves and wild-life refuges. With care and specially made 'hides' they may get a reasonable view. In marine reserves, with just a mask and snorkel, a child can not only see the fish, she can swim *with* them. Unless she makes a big fuss, the fish mostly ignore her and go about their own business. In a marine reserve, the fish learn that people are harmless, and treat them like passing cloud shadows. So the children get amazing experiences, close up to wild creatures. But *only* in an established marine reserve. Elsewhere, what fish there are tend to flee on the sight of people.

I think we should have marine reserves within easy access of every school in the country. They should be in the best places, and have priority over exploitive users. Such a programme would get the active political support of most parents. The reserves should have permanently-mounted underwater cameras (like CCTVs) in the bits too difficult or dangerous for snorkelling or glass-bottomed boats; and on-shore viewing rooms for these. Such reserves would be welcomed by scientists and recreational divers and could be accepted by the fishing authorities without them having to admit the reserves could also assist fishing stocks.

6. Conclusions

The pioneering experience of New Zealand with highly-protected marine reserves has shown that such reserves deliver a wide range of benefits to science, conservation and general management. These benefits are so important and valuable that it is clearly sensible to develop a system of reserves designed to maximise these benefits. New Zealand is still developing marine reserves and the existing set is not yet an ideal system, but it is sufficient to demonstrate the principles needed for such a system. In 2002 an international team of experts came to New Zealand to consider this. Their final report CBD (2004) detailed the principles required. A summary of these is given in Ballantine and Langlois (2008). The principles are:

- *Representation*: By definition, biogeographic provinces (and major habitats within them) have different biota. Consequently, a system of marine reserves to maintain the full range of marine life must include representative reserves in all regions and each major habitat in each region. Full representation is vital. The system must include all seascapes, habitats, depths; wave and current exposures, so as to encompass all the possible biodiversity.
- *Replication*: Within each region and major habitat there should be several spatially-separate marine reserves. This will comply with the old proverb 'Do not put all your eggs in one basket'. It is necessary to prevent single local accidents from wiping out any biota. Such accidents can be man-made, like oil-tanker spills or natural, like cyclones, volcanic eruptions or diseases. Replication is also a basic principle of science, and considering the variability in the environment, is essential for scientific understanding.
- *Geographically widespread network*: There are many reasons for this, including spreading the benefits through the region (e.g. school access); but the primary reason is to ensure that the system can work as a whole. Many marine species have their local recruitment de-coupled from their reproduction because the eggs and/or larvae are released into the sea and dispersed for a significant time by local currents before settling down to adult life. This means that a single marine reserve may not be self-recruiting (unless it is very large for some species). Although this is a serious problem when trying to create single reserves, it can be used to great advantage in designing a system. A well-designed network does not seek to optimise any particular exchange; rather it aims to create many possible routes for all exchanges. With a network of marine reserves, eggs and larvae from one reserve can drift to and supply other reserves. Detailed knowledge is not required, indeed the processes will certainly be different for various species (because of different larval life-spans); for different regions (because of different current patterns); and in different years (because of inter-annual variation in fecundity and currents).
- *Self-sustaining total area*: The final, and most important principle, defines the size of the system. The system must be sufficiently large in area to maintain itself through time, independently (as far as possible) of the surrounding seas. This amount cannot be calculated with any precision, but general principles allow us to give useful guide-lines. For the purposes of science and education (and recreation and information to general management) the system would need at least 10% of all areas. For the conservation of marine biota, the system would need at least 20% of all areas. (In the two systems so far created, detailed scientific investigations proposed a minimum of 25% of all areas, see below for more detail). For the maximum benefit to fisheries, the total area should be at least 30%, as calculated from computer models. Before dismissing this as 'merely computer modelling' it should be remembered that all existing fisheries management in advanced countries is based on computer modelling using the same data.

These principles for marine reserve systems are based on fundamental human and ecological features which apply world-wide. If other countries wish to by-pass the long struggle for marine reserve that occurred in New Zealand, they can go directly to systems, using these principles. This has already started to happen. In 2002, after more than a decade of consultation, the State of Victoria in Australia established 24 no-take areas (including 10 Marine National Parks) totaling 540 sq km and more than 5% of State waters (Sobel and Dahlgren, 2004). This was the world's first representative system of marine reserves. In 2003, the California Fish and Game Commission approved 10 'no-take' marine reserves in the northern Channel Islands, following a review of the previous Marine Sanctuary. The initial zones only covered state waters (out to 3 nautical miles), but later the federal authorities extended these to 6 nm. The reserves comprised 25% of waters around the islands and formed the first replicated and representative marine reserve system. In 2004, the Great Barrier Reef Marine Park Authority's new zoning plan was approved by the Australian Federal Government (Sobel and Dahlgren, 2004). The plan required a minimum of 25% by area of all 73 bioregions in the Park to be completely 'no-take'. This created the first marine reserve system using all the principles detailed above.

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The progress of marine reserves world-wide shows strong parallels to their history in New Zealand. Very slow at first; sporadic in both timing and space; unpredictable in detail; but continuing to develop. I may not live to see marine reserve systems generally in place round the world (I am 75), but I am confident my children will see it happen, and that my grandchildren will merely ask why such an obviously sensible idea took so long.

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References

*References marked * are available as pdf at www.marine-reserves.org.nz.*

Andrew, N.L., MacDiarmid, A.B., 1991. Interrelations between sea urchins and spiny lobsters in northeastern New Zealand. Mar. Ecol. Prog. Ser. 70, 211–222.

Appeltans, W., Ahyong, S.T., Anderson, G., Angel, M.V., Artois, T., Bailly, N., Bamber, R., Barber, A., Bartsch, I., Berta, A., Błażewicz-Paszkowycz, M., Bock, P., Boxshall, G., Boyko, C.B., Brandão, S.N., Bray, R.A., Bruce, N.L., Cairns, S.D., Chan, T.Y., Chan, L., Collins, A.G., Cribb, T., Curini-Galletti, M., Dahdouh-Guebas, F., Davie, P.J.F., Dawson, M.N., De Clerck, O., Decock, W., De Grave, S., de Voogd, N.J., Domning, D.P., Emig, C.C., Erséus, C., Eschmeyer, W., Fauchald, K., Fautin, D.G., Feist, S.W., Fransen, C.H.J.M., Furuya, H., Garcia-Alvarez, O., Gerken, S., Gibson, D., Gittenberger, A., Gofas, S., Gómez-Daglio, L., Gordon, D.P., Guiry, M.D., Hoeksema, B.W., Hopcroft, R., Jaume, D., Kirk, P., Koedam, N., Koenemann, S., Kolb, J.B., Kristensen, R.M., Kroh, A., Lambert, G., Lazarus, D.B., Lemaitre, R., Longshaw, M., Lowry, J., Macpherson, E., Madin, L.P., Mah, C., Mapstone, G., McLaughlin, P., Meland, K.L., Messing, C.G., Mills, C.E., Molodtsova, T.N., Mooi, R., Neuhaus, B., Ng, P.K.L., Nielsen, C., Norenburg, J., Opresko, D.M., Osawa, M., Paulay, G., Perrin, W., Pilger, J.F., Poore, G.C.B., Pugh, P., Read, G.B., Reimer, J.D., Rius, M., Rocha, R.M., Rosenberg, G., Saiz-Salinas, J.I., Scarabino, V., Schierwater, B., Schmidt-Rhaesa, A., Schnabel, K.E., Schotte, M., Schuchert, P., Schwabe, E., Segers, H., Self-Sullivan, C., Shenkar, N., Siegel, V., Sterrer, W., Stöhr, S., Swalla, B., Tasker, M.L., Thuesen, E.V., Timm, T., Todaro, A., Turon, X., Tyler, S., Uetz, P., van der Land, J., van Ofwegen, L.P., van Soest, R.W.M., Vanaverbeke, J., Vanhoorne, B., Walker-Smith, G., Walter, T.C., Warren, A., Williams, G., Wilson, S.P., Hernandez, F., Mees, J., Costello, M.J., 2012. The magnitude of global marine species diversity. Curr. Biol. 22, 1–14.

Babcock, R.C., Shears, N.T., Alcala, A.C., et al., 2010. Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. Proc. Nat. Acad. Sci. USA 107 (18), 256–261.

Babcock, R.C., Kelly, S., Shears, N.T., Walker, J.W., Willis, T.J., 1999. Large scale habitat change in marine reserves. Marine Ecology Progress Series 189, 125–134.

*Ballantine, W.J., 1991 Marine Reserves for New Zealand. Leigh Laboratory Bulletin. University of Auckland, 25, 196pp.

*Ballantine, W.J., 1995. The New Zealand experience with "no-take" marine reserves. In: Roberts et al. (1995), Review of the Use of Marine Fisheries Reserves in the U.S. Southeastern Atlantic. NOAA Technical, Memorandum NMFS-SEFSC-376. 31pp.

*Ballantine, W.J., 1996 "No-take" marine reserve networks support fisheries. In: Hancock, D.A. et al. (Eds.), Developing and Sustaining World Fisheries Resources: The state of Science and Management. 2nd World Fisheries Congress. 702–706 CSIRO Publishing, Collingwood, Australia.

*Ballantine, W.J., 1999 Marine Reserves in New Zealand: the development of the concept and the principles. In: Proceedings of an International Workshop on Marine Conservation for the new Millenium. Korean Ocean Research and Development Institute. Chefu Island, Korea.

Ballantine, W.J., Gordon, D.P., 1979. New Zealand's first marine reserve, Cape Rodney to Okakari Point, Leigh. Biol. Conserv. 15, 273–280.

*Ballantine, W.J., Langlois, J., 2008. Marine reserves: the need for systems. Hydrobiologia 606, 35–44.

Bohnsack, J.A., 1999. Incorporating no-take marine reserves in precautionary management and stock assessment. In: Proceedings of 5th National Marine Fisheries Service NSAW. NOAA Tech. Memo. NMFS-F/SPO-40.

Bohnsack, J.A., 2003. Shifting baselines, marine reserves and Leopold's biotic ethic. Gulf Carribbean Res. 142, 1–7.

CBD (Convention on Biological Diversity). 2004 Technical Advice on the Establishment and Management of a National System of Marine and Coastal Protected areas Secretariat of the Convention of Biological Diversity. CBD Technical Series 13, 40pp.

Chapman, V.J., 1957. Marine algal ecology. Bot. Rev. 23, 320–350.

Chapman, V.J., 1974. Salt Marshes and Salt Deserts of the World. J. Cramer, Lehre, 392p.

Chapman, V.J., 1976. Coastal Vegetation. Pergamon Press, New York, 292p.

Claudet, J. (Ed.), 2011. Marine Protected Areas: A Multidisciplinary Approach. Cambridge University Press, 377pp.

Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., Miloslavich, P., 2010. A census of marine biodiversity knowledge, resources and future challenges. PLoS ONE 5 (8), e12110.

Costello, M.J., Wilson, S.P., Houlding, B., 2012. Predicting total global species richness using rates of species description and estimates of taxonomic effort. Syst. Biol. 61 (5), 871–883.

Costello, M.J., Wilson, S., Houlding, B., 2013a. More taxonomists but a declining catch of species discovered per unit effort. Syst. Biol. 62 (4), 616–624.

Costello, M.J., May, R.M., Stork, N.E., 2013b. Can we name Earth's species before they go extinct? Science 339, 413–416.

Costello, M.J., Bouchet, P., Boxshall, G., Fauchald, K., Gordon, D.P., Hoeksema, B.W., Poore, G.C.B., van Soest, R.W.M., Stöhr, S., Walter, T.C., Vanhoorne, B., Decock, W., Appeltans, W., 2013c. Global coordination and standardisation in marine biodiversity through the World Register of Marine Species (WoRMS) and related databases. PLoS ONE 8 (1), e51629. http://dx.doi.org/10.1371/journal.pone.0051629.

Dayton, P.K. et al., 1998. Sliding baselines, ghosts, and reduced expectations in kelp forest communities. Ecol. Appl. 8, 309–322.

Denny, C.M., Babcock, R.C., 2004. Do partial marine reserves protect reef fish assemblages? Biol. Conserv. 116, 119–129.

Department of Conservation. 1995. Poor Knights Islands Marine Reserve: Recreational Fishing Review. Discussion Paper. Department of Conservation, Whangarei, 15pp.

Department of Conservation. 2013. Marine Reserves. <http://www.doc.govt.nz/conservation/marine-and-coastal/marine-protected-areas/marine-reserves-a-z/> (accessed 2.10.13).

Edgar, G.J., Barrett, N.S., 1999. Effects of declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. J. Exp. Mar. Biol. Ecol. 242, 107–144.

Enderby, J., Enderby, T., 2006. A Guide to New Zealand's Marine Reserves. New Holland Publishers, Auckland, 173 pp.

Francis, M., 2012. Coastal fishes of New Zealand, fourth ed. Craig Potton Publishing, Nelson, New Zealand, 268 pp.

Gordon, D.P., Beaumont, J., MacDiarmid, A., Robertson, D.A., Ahyong, S.T., 2010. Marine biodiversity of aotearoa New Zealand. PLoS ONE 5(8), e10905. http://dx.doi.org/10.1371/journal.pone.0010905.

Hickman, R., 2010. Fifty Years of NZMSS: A History of the New Zealand Marine Sciences Society. New Zealand Marine Sciences Society, 105pp.

Hilbron, R., 1998. The economic performance of marine stock enhancement projects. Bull. Mar. Sci. 62, 661–674.

Jackson, J.B., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. science 293 (5530), 629–637.

Johnson, D.R., Funicelli, N.A., Bohnsack, J.A., 1999. Effectiveness of an existing no-take fish sanctuary within the Kennedy Space Center, Florida. North Am. J. Fish. Manage. 19, 436–453.

Kelly, S., Scott, D., MacDiarmid, A.B., 2002. The value of a spillover fishery for spiny lobsters around a marine reserve in northern New Zealand. Coast. Manage. 30, 153–166.

*Langlois, T.J., Ballantine, W.J., 2005. Marine ecological research in New Zealand: developing predictive models using no-take marine reserves. Conserv. Biol. 19, 1763–1770.

Langlois, T.J., Anderson, M.J., Babcock, R.C., 2005. Reef-associated predators influence adjacent soft-sediment communities. Ecology 86, 1508–1519.

Langlois, T.J., Anderson, M.J., Babcock, R.C., Kato, S., 2006. Marine reserves demonstrate trophic interactions across habitats. Oecologia 147, 134–140.

Leleu, K., Remy-Zephir, B., Grace, R., Costello, M.J., 2012. Mapping habitat change after 30 years in a marine reserve shows how fishing can alter ecosystem structure. Biol. Conserv. 155, 193–201.

Longhurst, A., 2010. The Mismanagement of Marine Fisheries. Cambridge University Press, 334pp.

Ludwig, D., Hilbron, R., Walters, C., 1993 Uncertainty, Resource Exploitation and Conservation: Lessons from History. Science 260, 17 and 36.

MacDiarmid, A.B., 1991. Seasonal changes in depth distribution, sex ratio and size frequency of spiny lobster *Jasus edwardsii* on a coastal reef in northern New Zealand. Mar. Ecol. Prog. Ser. 70, 129–141.

MacDiarmid, A.B., Freeman, D., Kelly, S., 2013. Rock lobster biology and ecology: contributions to understanding through the Leigh Marine Laboratory 1962–2012. NZ J. Mar. Freshwat. Res. 47 (3), 1–21.

McCook, L.J., Ayling, T., Cappo, M., Choat, J.H., Evans, R.D., De Freitas, D.M., Heupel, M., Hughes, T.P., Jones, G.P., Mapstone, B., et al., 2010. Adaptive management of the Great Barrier Reef: a globally significant demonstration of the benefits of networks of marine reserves. Proc. Natl. Acad. Sci. USA 107, 18278–18285.

Mulcahy, K., Peart, R., Bull, A., 2012. Safeguarding Our Oceans: Strengthening Marine Protection in New Zealand. Environmental Defence Society, Auckland, 380 pp.

New Zealand Government, 1971. Marine Reserves Act. (accessed <http://www.legislation.govt.nz/act/public/1971/0015/latest/DLM397838.html>.

Please cite this article in press as: Ballantine, B. Fifty years on: Lessons from marine reserves in New Zealand and principles for a worldwide network. Biol. Conserv. (2014), http://dx.doi.org/10.1016/j.biocon.2014.01.014

New Zealand Government, 2013 Sub-Antarctic Marine Reserves Bill, Wellington, N.Z.

Parsons, D.M., Babcock, R.C., Hankin, R.K.S., et al., 2003. Snapper *Pagrus auratus* (Sparidae) home range dynamics: acoustic tagging studies in a marine reserve. Mar. Ecol. Prog. Series 262, 253–265.

Pauly, D., 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends Ecol. Evol. 10, 430.

Pauly, D. et al., 1998. Fishing down the food webs. Science 279, 860–863.

Roberts, C., 2007. The Unnatural History of the Sea. Island Press, Washington, DC, 456pp.

Roberts, C. et al., 1995. Review of the use of Marine Fisheries Reserves in the U.S. Southeastern Atlantic. NOAA Technical, Memorandum NMFS-SEFSC-376, 31pp.

Rojas-Nazar, U., 2013 'Economic, Social, and Biological Evaluation of Two Marine Reserves Within New Zealand'. Unpublished PhD thesis, Victoria University of Wellington.

Salomon, A.K., Shears, N.T., Langlois, T.J., Babcock, R.C., 2008. Cascading effects of fishing can alter carbon flow through a temperate coastal ecosystem. Ecol. Appl. 18, 1874–1887.

Shears, N.T., Babcock, R.C., 2003. Continuing trophic cascade effects after 25 years of marine reserve protection. Mar. Ecol. Prog. Ser. 246, 1–16.

Shears, N.T., Babcock, R.C., Salomon, A.K., 2008. Context-dependent effects of fishing: variations in trophic cascades across environmental gradients. Ecol. Appl. 18, 1860–1873.

Sobel, J., Dahlgren, C., 2004 Marine Reserves: A Guide to Science Design and Use. Island Press, Washington, 383pp.

Taylor, R.B., 1998. Density, biomass and productivity of animals in four subtidal rocky reef habitats: the importance of small mobile invertebrates. Mar. Ecol. Prog. Ser. 172, 37–51.

Trippel, E.A., Kjesbu, O.S., Solemdal, P., 1997. Effects of adult age and size structure on reproductive output in marine fish. In: Chambers, R.C., Trippel, E.A. (Eds.), Early Life History and Recruitment in Fish Populations. Chapman and Hall, London.

Willis, T.J., Millar, R.B., Babcock, R.C., 2003. Protection of exploited fish in temperate regions: high density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand. J. Appl. Ecol. 40, 214–227.

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