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# **What are the ecological impacts of marine reserves in New Zealand?**

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*Prepared for*

Department of Conservation

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## Executive Summary

The New Zealand scientific literature regarding marine reserve effects was reviewed to determine "What are the ecological impacts of marine reserves in New Zealand?" Published studies have generally found differences in behaviour, abundance, size, and—in some cases—habitat organisation between reserve and non-reserve areas. Most of those differences are consistent with an effect of fishing; mainly removing larger individuals from populations. The marine reserves that have been established longest exhibit quite different habitat structure from nearby fished areas, consistent with a 'trophic cascade' in which increased numbers of large predators have reduced populations of grazing sea urchins, allowing seaweed forests to replace the coralline-dominated areas. These effects are of international significance and interest. Such trophic cascade effects have not emerged to date in more southern marine reserves, which have not been protected for as long as the northern ones. However, in all of the studies reviewed there was evidence of change in some heavily exploited species. The definitive standard of evidence for demonstrating marine reserve effects—as outlined in a recent review—has not been met in New Zealand, or anywhere else. Better data regarding ecological habitats, abundances, size structures and behaviour of organisms, and on the catches of fishers themselves, will need to be collected both inside and outside reserves, before and after reserve establishment, to meet those standards.

# 1 Introduction

There is currently intensive interest in marine reserves as an alternative fishery management option in the northern hemisphere. New Zealand is in the internationally privileged position of having had numerous fully-protected marine reserves for 5 or more years. Furthermore, there have been numerous studies of the impacts of protection. Here I review the published literature regarding the ecological impacts in New Zealand marine reserves (Table 1). After documenting the evidence regarding the ecological impacts of reserves, as set out in Section 2 and summarised as a table in the Appendix, I consider the wider implications, and some technical matters.

**Table 1 Abbreviations for names of marine reserves.**

Abbreviation	Name of reserve
CROPMR	Cape Rodney to Okakari Point Marine Reserve
TIMR	Tonga Island Marine Reserve
TMP	Tawharanui Marine Park
TMR	Tuhua Marine Reserve
TWAHMR	Te Whanganui a Hei Marine Reserve
LIKMR	Long Island Kokomohua Marine Reserve

## 2 Ecological impacts of marine reserves in New Zealand

### 2.1 Effects on behaviour

#### 2.1.1 Mechanism

Fish may become accustomed to humans that do not pursue them, or may change behaviour through humans feeding them. This may be assessed via passive (how closely fish approach humans) and active (how closely humans can approach fish) sampling.

### 2.1.2 Case studies

Cole et al. (1990) alluded to, but did not quantify, changes in behaviour of snapper within CROPMR compared to adjacent fished areas.

Cole (1994) described patterns of diver-responsiveness of snapper and blue cod within CROPMR. Snapper approached divers more, and allowed divers to approach more closely, at sites in the centre of the reserve, than at sites further from the centre of the reserve.

Willis et al. (1998) clarified movement of reef-associated snapper using VIFE tags at CROPMR, but did not tag animals outside the reserve.

Cole et al. (2000) sampled dispersal of tagged blue cod at LIKMR and nearby fished sites. Greater dispersal occurred at the reserve site, but this was based on relatively few individuals. Overall the range of movements was small, with most resights occurring within 100 m of the tagging site, and the most distant resights occurring at less than 450 m.

Kelly (2001) tagged spiny lobsters inside CROPMR and TMP and recorded them outside the reserve boundaries, but did not examine movement of lobsters tagged outside reserves.

Willis et al. (2001) studied movements of snapper within CROPMR. They found that some snapper were resighted within the same area (within 500 m of where they were tagged) for up to 4 years.

Kelly & MacDiarmid (2003) analysed movement of spiny lobsters at CROPMR. They found 21% of tagged lobsters remained associated with one reef for 1-8 years. There were sex-related patterns in movement, with larger individuals of both sexes moving less. Twenty percent of tagged lobsters crossed the reserve boundaries. The authors concluded that a proportion of the lobster population was subject to fishing because they crossed the reserve boundary. Similar conclusions were reached by Kelly et al. (2002).

O'Dor et al. (2001) sampled movement of tagged snapper *Pagrus auratus* at CROPMR. They found that the fish showed considerable site attachment, spending most of their time in areas up to 400 m radius and, in some cases, as small as 50 m

radius. However, several individual fish demonstrated movements that spanned a few hundred metres over ca 4 hr.

### **2.1.3 Commentary**

Exploited fishes commonly are more approachable in marine reserves. Where there are many divers this may represent a response to feeding of fish. However, alterations of behaviour in reserves that are not intensively dived (e.g. LIKMR) and observations in remote areas (e.g. Kermadecs R. Cole pers. obs.) suggest that fishes are often merely curious regarding divers, and that the behaviour of fishes outside marine reserves may be unnatural and modified by exploitation. It is not clear how such effects may influence diver counts, but numerous experimental approaches to the problem exist.

Design of marine reserves requires good information regarding dispersal of organisms. As yet we are unable to predict dispersal of many species; reef-associated snapper may move little (Willis et al. 1998, O'Dor et al. 2001, Willis et al. 2001) but individuals that are not reef-associated may move further (Crossland 1976, Gilbert et al. 2001). Gilbert & McKenzie (1999) estimated home ranges for snapper away from reefs as 10-20 km, whereas Willis et al. (2001) found that most of the resights occurred within a 500 m radius of the tagging site. More intensive studies of movement of target species, such as those currently being undertaken at CROPMR, will allow more informed marine reserve design for those species.

## **2.2 Effects on abundance**

### **2.2.1 Mechanism**

Harvesting removes organisms from populations outside marine reserves, hence it is expected that marine reserves might lead to increases in abundance of exploited species. A number of studies have described such effects in New Zealand marine reserves.

### 2.2.2 Case studies

McCormick & Choat (1987) compared abundance of red moki *Cheilodactylus spectabilis* at CROPMR with those of an adjacent fished area. The study was habitat-stratified, and they found that density was 2.3 times higher in the reserve than outside.

Kingsford (1989) included PKIMR and CROPMR in his study of planktivorous fishes, but there was no discussion of marine reserve effects.

Cole et al. (1990) sampled abundances of fishes, sea urchins, and spiny lobsters inside the CROPMR and on the adjacent coast in a one-off survey. They also included data from earlier surveys within the reserve (dating back to 1976) for particular sites, and further paired comparisons between fixed sites in 1978 and 1988. Abundances of snapper, goatfish, spotty, blue cod and leatherjacket did not show clear long term increases in abundance over the period 1976-1982, whereas red moki did. Comparison of data from 1978 and 1988 indicated that, in the shallow broken rock habitat (SBR), abundance of goatfish appeared to have declined at 2 of 5 sites, abundance of hiwihivi was lower at 4 of 5 sites, and abundance of red moki was lower in 1 of 5 sites. In the rock flats (RF) habitat there were consistent declines in the abundance of snapper from 1978 to 1988. As this comparison is confounded with different divers and potentially with habitat, it should be treated with caution.

Data from the one-off survey showed that the density of sea urchins did not differ between CROPMR and non-reserve areas, whereas those of spiny lobster did. In the SBR habitat snapper, leatherjacket, butterfly and red moki were more abundant in the reserve than outside, and parore were more abundant outside the marine reserve. Red moki were more abundant inside the reserve in RF habitat, and snapper, blue cod and red moki were more abundant in the reserve in kelp forest (KF) habitat, whereas goatfish were more abundant outside the reserve. Using an arbitrary criterion (the number of comparisons with non-overlapping error bars), 13 of 26 comparisons had higher means in the reserve, 9 comparisons had overlapping error bars, and four had higher means outside the reserve. Cole et al. (1990) found more small snapper outside the reserve, a pattern that has also been noted by Willis et al. (2003).

MacDiarmid & Breen (1993) included temporal and spatial comparisons in their study of spiny lobsters at PKIMR and CROPMR. They found higher densities within the marine reserve than in five nearby fished areas.



Cole (1994) documented patterns of abundance of blue cod, red moki, and snapper within CROPMR in 1991, and found clear gradients of blue cod and snapper within the reserve; there were more snapper in the central part of the marine reserve. This pattern has been consistently documented for snapper (e.g. Willis et al. 2000).

Babcock et al. (1999) found that snapper were ~6-9 times more abundant, and that spiny lobsters were 1.6-3.7 times more abundant in CROPMR and TMP, than nearby fished areas.

Willis & Babcock (2000) sampled snapper and blue cod inside and outside TWAHMR. They found greater abundances of snapper (2.6x) and blue cod (2.4x) in the reserve area than in the fished area with baited underwater video (BUV). Divers estimated 4.2x as many blue cod in the reserve area than in the fished area.

Willis et al. (2000) sampled snapper and blue cod using three methods (underwater visual census—UVC, angling, BUV) inside and outside CROPMR. They found that all sampling methods indicated higher abundances of snapper at the reserve centre, and that all 3 methods estimated a minimum (lower 95% confidence interval (CI) on reserve: non-reserve ratio) of about twice as many snapper in the reserve to outside. Density of blue cod was higher within the reserve for all three methods, but the lower CI's on the ratios were 1.55 (UVC), 2.03 (angling), and 1.20 (BUV).

Kelly et al. (2000) compared spiny lobster recovery in 4 marine reserves (CROPMR, TMP, TWAHMR, TMR) of varying ages. They estimated annual rates of increase in density following marine reserve establishment to be 3.9% in shallow sites (<10 m depth) and 9.5% in deep sites (> 10 m depth).

Davidson (2001) used several sampling methods to demonstrate that blue cod density was greater in LIKMR than in adjacent fished areas. Diver transects showed that blue cod density was higher within the reserve throughout the study, but as there had been a moratorium on fishing in the area for several years prior to the formal establishment of the reserve, it is not clear when the reserve effect on density was established.

Davidson et al. (2002) estimated that spiny lobsters were 2.8 times more abundant overall inside TIMR than on adjacent fished coasts. They also estimated that large reproductive males were 10 times more abundant within the reserve compared to outside. The rate of population increase was estimated to be 4.4% per annum within the reserve, whereas outside the reserve the population was estimated to have decreased by 2.9% per annum.

Estimates of total snapper abundance with BUV in 3 marine reserves were 2.5 (CROPMR), 4.2 (TWAHMR), and 2.1 (TMP) times higher than estimates of the numbers in adjacent fished areas (Willis et al. 2003). The same effects as for total snapper abundance were apparent when snapper greater than minimum legal size (MLS) were considered, but the pattern was inconsistent for juvenile snapper.

Cole et al. (submitted) compared abundances of fish inside and outside 3 marine reserves (TIMR, LIKMR, CROPMR) by use of 3 different methods (scuba divers, rebreather divers, and BUV). They found that abundances of blue cod were similar at LIKMR compared to adjacent fished areas with all 3 sampling methods. Their data also show goatfish to be more abundant outside CROPMR, a pattern also found by Cole et al. (1990). Mean abundances of snapper were higher in CROPMR than at adjacent fished areas with both scuba and rebreather, but the main effect of reserve status was statistically non-significant in the analysis. Abundances of common species were similar for all sampling methods at LIKMR. At TIMR there were no obvious effects on abundance of any species.

Denny et al. (in prep.) compared abundances of fish using 2 sampling methods—BUV and diver counts—at PKIMR, and two comparable fished areas ('reference' sites). They found that abundances of snapper were consistently higher within the marine reserve, with both methods of sampling. BUV indicated that snapper >270 mm fork length (minimum legal size, MLS - 'legal snapper') increased by 9.4 times, whereas diver counts were unable to demonstrate a difference in numbers of legal snapper. Densities of snapper in partially protected areas (which were previously subject to fishing regulations limiting the type of gear used) were initially lower than the two fully-protected parts of PKIMR, but that species then recovered rapidly.

Denny et al. (in prep.) also found that numbers of blue maomao, koheru, pink maomao, and orange wrasse in diver counts increased in the reserve, whereas BUV indicated that scorpion fish increased over time. For several of these species however, abundance had always been higher in the reserve than in the fished areas. Abundances of eight species decreased over time in the reserve, whereas only one species decreased in abundance at each of the reference areas.

Pande et al. (unpubl.) compiled data on blue cod (5 studies) and spiny lobster (10 studies) abundance from a number of unpublished sources. They found that older reserves showed greater effects on blue cod abundance, but the effects of reserve size and of latitude were not strong. There were strong positive effects of reserve age on effect size for spiny lobster abundance, more northern reserves have stronger positive

effects on lobster abundance, but size of reserve appeared to have little association with magnitude of effect. The study used meta-analysis, a statistical method of summarising the results of multiple studies.

### 2.2.3 Commentary

The overwhelming impression from these studies is that marine reserves increase the abundances of fished species. Such effects are best-documented at CROPMR and other northern reserves, but the focussed study by Davidson (2001) at LIKMR also provides clear evidence that reserves in more southern areas have similar effects. There are also additional studies from Kapiti (NIWA unpubl.) which support this pattern. The absence of detectable effects on fish populations (though not spiny lobster populations) at TIMR (Cole et al. submitted) is presumably because there are few large exploited species whose individuals remain resident in the area.

The absence of repeated sampling inside and outside of marine reserves before their establishment in nearly all cases means that the case for an individual marine reserve being the cause for the increase is not completely secure. Although the evidence is generally overwhelming that it is the reserve status that is responsible for differences from the fished areas, the evidence demonstrating reserve effects is somewhat weak in this regard. Monitoring of the proposed marine reserve at Paterson Inlet, Stewart Island has now extended for many years, and it will offer strong evidence for effects. In many cases, however, proponents of marine reserves implement voluntary bans on fishing before marine reserve establishment, making it difficult to discern when protection was truly established. Measures of fishing effort, inside and outside proposed reserve areas would supplement evidence for effects of reserves (see also Section 3.5).

Discerning the reliability of diver surveys of mobile organisms is difficult. The use of several sampling methods by some studies (Willis et al. 2000, Davidson 2001, Cole et al. submitted) is useful. Those studies generally suggest that diver surveys produce similar patterns to alternative methods, indicating that the general use of diver counts is justified, and that BUUV can be a useful and cheap adjunct for target species.

Diver counts fail to detect snapper in northern South Island New Zealand, though fishers catch them there, and they have been observed with cable video attracted to baits in several areas (N. Alcock, unpubl. video). It is clear that the behaviour of that species differs between northern New Zealand and more southern areas. More

information regarding how fish behave in relation to divers, and how that may change with acclimation to divers, would assist.

## **2.3 Effects on size / biomass**

### **2.3.1 Mechanism**

Individuals that remain within marine reserves live longer than those in fished areas. Older individuals are usually larger than younger ones, and therefore marine reserves may contain larger individuals.

### **2.3.2 Case studies**

McCormick & Choat (1987) found that 38% of the red moki were larger than 300 mm in a fished area, whereas 62% were of that size within CROPMR.

Cole et al. (1990) observed more larger snapper in CROPMR than on adjacent fished coasts.

MacDiarmid & Breen (1993) documented larger spiny lobsters within CROPMR than at adjacent fished areas. However, PKIMR did not demonstrate a similar response.

Cole (1994) found more large snapper and blue cod in the central part of CROPMR than in areas toward the edge.

Cole & Keuskamp (1998) sampled sea urchin sizes inside and outside two marine reserves. They found larger non-crevice-bound individuals at CROPMR than at adjacent fished sites, but the same patterns did not occur in comparisons of TMP with Kawau Island, or of PKIMR with Mokohinau Islands. That study also sampled carnivorous fishes, and documented both larger fish of a range of species, and also larger harvested fish, in CROPMR than at adjacent fished areas.

Willis & Babcock (2000) estimated sizes of snapper and blue cod with BUV at TWAHMR and found that reserve snapper were about 70 mm larger, and reserve blue cod were about 100 mm larger, than nearby fished areas.

Willis et al. (2000) used angling, BUV and diver counts to demonstrate that snapper and blue cod sizes were larger (about 100 mm and 40 mm respectively) within CROPMR than at adjacent fished areas.

Kelly et al. (2000) sampled 4 northeastern New Zealand marine reserves of varying ages. Lobster biomass was estimated to increase by 5.4% per annum in shallow sites, and 10.9% per annum in deep sites. Egg production was estimated to increase by 4.8% and 9.1% per annum for shallow and deep sites respectively.

Davidson (2001) used angling and diver counts to show that blue cod were larger in LIKMR than at nearby fished areas. This long-term study showed that it took several years before blue cod size in the reserve became larger than at nearby fished areas.

Davidson et al. (2002) found that within TIMR average spiny lobster carapace length was 19 mm larger in shallow transects, and 28 mm larger in deep transects compared to non-reserve sites.

Willis et al. (2003) sampled snapper in 3 marine reserves (CROPMR, TWAHMR, TMP), and found biomass ratios for reserve: non-reserve of between 4 and 12. In all cases lower 95% confidence intervals were greater than 2. Comparisons of raw size indicated that the mean differences ranged from about 60 mm to 144 mm for all snapper, and from 24 to 104 mm for snapper greater than MLS. Similar ratios were found for egg production, except that the ratios ranged from nearly 7 to more than 23, and that the minimum lower 95% CI was 3.61.

Cole et al. (submitted) used data from scuba and rebreather divers, and from BUV, to show that blue cod sizes at LIKMR were clearly larger than nearby fished areas. They could not demonstrate clear differences for snapper at CROPMR, mainly because of small sample sizes in the diver samples (particularly outside the reserve). No fish species was sufficiently abundant to compare sizes among methods at TIMR.

Denny et al. (unpubl.) described sizes of snapper at PKIMR and 2 reference areas. Mean length was always greater in BUV samples at PKIMR than at the reference stations, but it did not show a consistent increase of mean size. Biomass estimates at PKIMR, however, increased more rapidly between 1998 and 2002 than at the reference stations.

Pande et al. (unpubl.) compiled data on sizes of blue cod and spiny lobster from a number of unpublished sources and subjected them to meta-analysis. They found

unclear effects of reserve age and reserve size on blue cod size, but there was an indication that southern reserves responded more clearly than northern ones. However, as there was only one northern reserve (Te Angiangi), and there were only 5 reserves considered, the pattern was uncertain. For spiny lobsters there were 10 comparisons, and older, more northern, reserves had greatest effects. There was no clear effect of size of reserve on the effect size.

### **2.3.3 Commentary**

There is a straightforward link between increased survivorship, greater longevity, and larger size of exploited populations in reserves. Note that there are no age data from marine reserves. Age data would allow more detailed comparisons of the benefits of marine reserves for organisms to be examined; e.g. provide answers to the question, do fish grow faster in marine reserves? One example of interest to scientists would be to understand whether there are density-dependent effects on growth. Less obvious effects on size may occur however. For example, prey organisms may be consumed in a size-selective manner. If the preference of predators is for large individuals of the prey species, smaller individuals may dominate populations in marine reserves (e.g. *Evechinus* size data in Shears & Babcock 2003). Similar effects might emerge over time for small fishes where large piscivorous (fish-eating) fishes recover strongly.

## **2.4 Effects on assemblage structure and composition**

### **2.4.1 Mechanism**

If species are hunted to extinction outside reserves there may be effects on species richness. There are studies suggesting that some fishes are presently in that position (Casey & Myers 1998). Sustained predation pressure from higher abundances and larger sizes of predatory organisms in marine reserves may affect other organisms ("trophic cascades").

### **2.4.2 Case studies**

Cole et al. (1990) made a habitat-stratified comparison of number of fish species between reserve and non-reserve areas at CROPMR in 1988. They found consistently greater species richness inside the reserve than outside. It is possible that this was not effect of marine reserve protection, but simply a feature of the marine reserve locality.

Babcock et al. (1999) documented long-term changes in benthic habitat at CROPMR, finding greatly suppressed cover of coralline flats and much greater cover of kelp forest in the reserve than at adjacent fished areas.

Shears & Babcock (2002) found greater representation of turfs and lower representation of crustose corallines in CROPMR than in nearby fished areas.

Shears & Babcock (2003), working at CROPMR, found that mixed algae was 3.6 times more likely to occur at reserve sites than at nearby fished areas, and that kelp forest was 2.7 times more likely to occur there. They also noted that coralline-dominated habitats had further declined from the Babcock (1999) study at several sites.

Cole et al. (unpublished ms) compared species richness of transect samples inside and outside marine reserves (CROPMR, TIMR, and LIKMR), and used a novel statistical method to show that the species richness inside and outside lay within a 50% equivalence interval, i.e. they were equivalent.

### 2.4.3 Commentary

To date effects on assemblage structure have only emerged in northeastern New Zealand, where marine reserves have been established for decades. It is uncertain whether similar effects will emerge elsewhere; certainly the primary response of large carnivores such as blue cod and spiny lobster at some southern marine reserves (e.g. Davidson 2001, Davidson et al. 2002) is sufficient to impose a severe predatory field on herbivorous prey.

## 3 Discussion

### 3.1 Species considered

Which species should be included in surveys of marine reserve effects? Fished species, particularly ones that move relatively little, are those which will demonstrate effects most clearly. Rapidly growing species will accumulate biomass most rapidly, whereas those with consistent high recruitment should demonstrate effects on density rapidly. Most of the recent published studies have focussed on species that are subject to fisheries (for obvious reasons: it is much more efficient to sample abundant species, and more satisfying to conclude that there is a difference). The absence of reserve

effects on unfished species, however, offers an indication that it is fishing, rather than a location effect, that is responsible for changes in abundance. This is alluded to by Kelly et al. (2000), who sampled 4 marine reserves and adjacent control areas, and reviewed international literature to demonstrate that conclusions of reserve effects in the literature may be premature (see also Willis et al. in press). Notwithstanding secondary effects (such as changes in behaviour), it is desirable to maintain the use of scuba diver counts for such data, because of the greater range of species that they may be able to reliably sample.

### **3.2 Reserve size**

As the number of reserves increases, and the detail of studies increases, more information is available to advise Department of Conservation on marine reserve size. The effectiveness of marine reserve protection depends partly on the size of the reserve in relation to movements of the species. This has been most clearly investigated for spiny lobster, where studies have shown lobsters moving beyond CROPMR boundaries (Kelly 1999). At CROPMR, the consistent decline of snapper abundance away from the centre of the reserve (e.g. Cole 1994, Willis et al. 2000), in combination with more recent studies of snapper movement (Willis et al. 2001, O'Dor et al. 2001) is consistent with an effect of fishing depleting snapper abundances within the reserve near its boundaries.

Understanding the likelihood of dispersal of adults across reserve borders requires reliable data on movement. There is little New Zealand information available regarding the movement of reef-associated organisms, though lobsters and commercially important fishes have been studied in some detail (e.g. Cole et al. 2000, Kelly & MacDiarmid 2003). Tagging studies of fishes on coastal reefs (e.g. blue cod - Cole et al. 2000, snapper - Willis et al. 2001) have generally found more limited movements than those offshore (e.g. blue cod - Carbines 1999, snapper - Gilbert et al. 2001). Tagging more fish, and sampling at greater distances from reserves will allow the proportion of fish that disperse more widely to be estimated more reliably. Estimating the exchange of fish between reefal populations and those offshore will also be important. Tagging, although intrusive, will be the primary tool in such studies, and it will be necessary to tag fish in marine reserves (and outside them) to predict the potential effects of marine reserves.



### 3.3 Methodology

Two recent studies (Rochet & Trenkel 2003, Trenkel & Rochet 2003) consider indicators of abundance that might measure the impact of fishing, based on data typically available for fisheries. It would be expected that marine reserve effects would be equally well-addressed by such indicators (i.e. they should work equally as indicators of absence of fishing). Trenkel & Rochet (2003) concluded that mean length of catch was useful; mean length of individual or in BUV sets in transects might be an equivalent metric for reef fishes. Useful comparisons could be made using existing data for such indicators. There is considerably more work to be done, probably on existing data, concerning the duration of studies, the methods, and the allocation of effort to sampling, that would produce robust efficient reserve monitoring programmes. Information regarding which species are captured, for example from diary surveys of angler catches, would assist those compilations.

Most ecology is done within a framework of testing null hypotheses, in which it is impossible to conclude that two populations are the same. Frequently studies are unable to demonstrate differences, and sometimes that is used incorrectly to conclude that there are no differences. There are other statistical frameworks that allow the conclusion that two populations are equivalent, within a specified interval (McDonald & Erickson 1993, McBride 1999, 2002). There exist ecological examples of the use of equivalence testing (e.g. McDonald & Erickson 1993, McBride 1999, Cole et al. 2001). Analysing the fish count data of Cole et al. (unpublished) at Leigh via these methods, only number of species consistently allows a conclusion of either difference or similarity. Even when rebreather and scuba counts are pooled together, only numbers of species and numbers of individuals were able to be demonstrated to be equivalent between reserve and fished areas, with a 50% equivalence interval. The abundances of goatfish were able to be demonstrated to be different, with greater abundances outside the reserve. Greater attention to sampling methods, and more sampling effort is likely to be required for robust conclusions.

The related issue of "publication bias" has been little considered with respect to marine reserve effects (Mosquera et al. 2000, Halpern & Warner 2002, Halpern 2003), but could be very important. The published international literature of empirical studies overwhelmingly indicates that there are positive effects of marine reserves (Halpern 2003). However, this may be biased if studies which fail to detect effects are not published (see Jennions & Moller 2002). Because statistical significance is the most widely used measure of detecting an effect, large studies of species that are exploited are those most likely to be published. Another potential source of bias is that workers choose to investigate species or situations where there is likely to be an effect

(workers are likely to study species that appear to show effects). This is more difficult to counter, and the recent Willis et al. and Davidson et al. publications tend to focus on target species that are likely to demonstrate responses. Studies that sample the entire fish assemblage (e.g. by divers) have the advantage that they can demonstrate differences in the patterns shown by exploited and unexploited species, and that secondary effects may be detected.

I used the "trim and fill" method (Jennions & Moller 2002) to investigate 'publication bias' in the density datasets reviewed by Halpern (2003) (Figure 1). The method estimated that about 5 studies with small or negative effects of marine reserve protection on abundance were missing from that review. However, the data of Halpern (2003) comprise reserves of widely varying ages and often uncertain protection status. A more relevant analysis would be of New Zealand marine reserves, using per annum increase rates (as calculated by Kelly et al. 2000) to remove the effects of reserve age. Pande et al. (unpubl.) have compiled the raw data for spiny lobster and blue cod that would allow such an analysis of New Zealand marine reserves. Although Halpern (2003) weighted a study of numerous species as only one study, there is considerable potential to use unexploited species surveyed inside and outside reserves to act as 'controls' in some way (Mosquera et al. 2000), provided robust information regarding levels of exploitation of different species can be established.

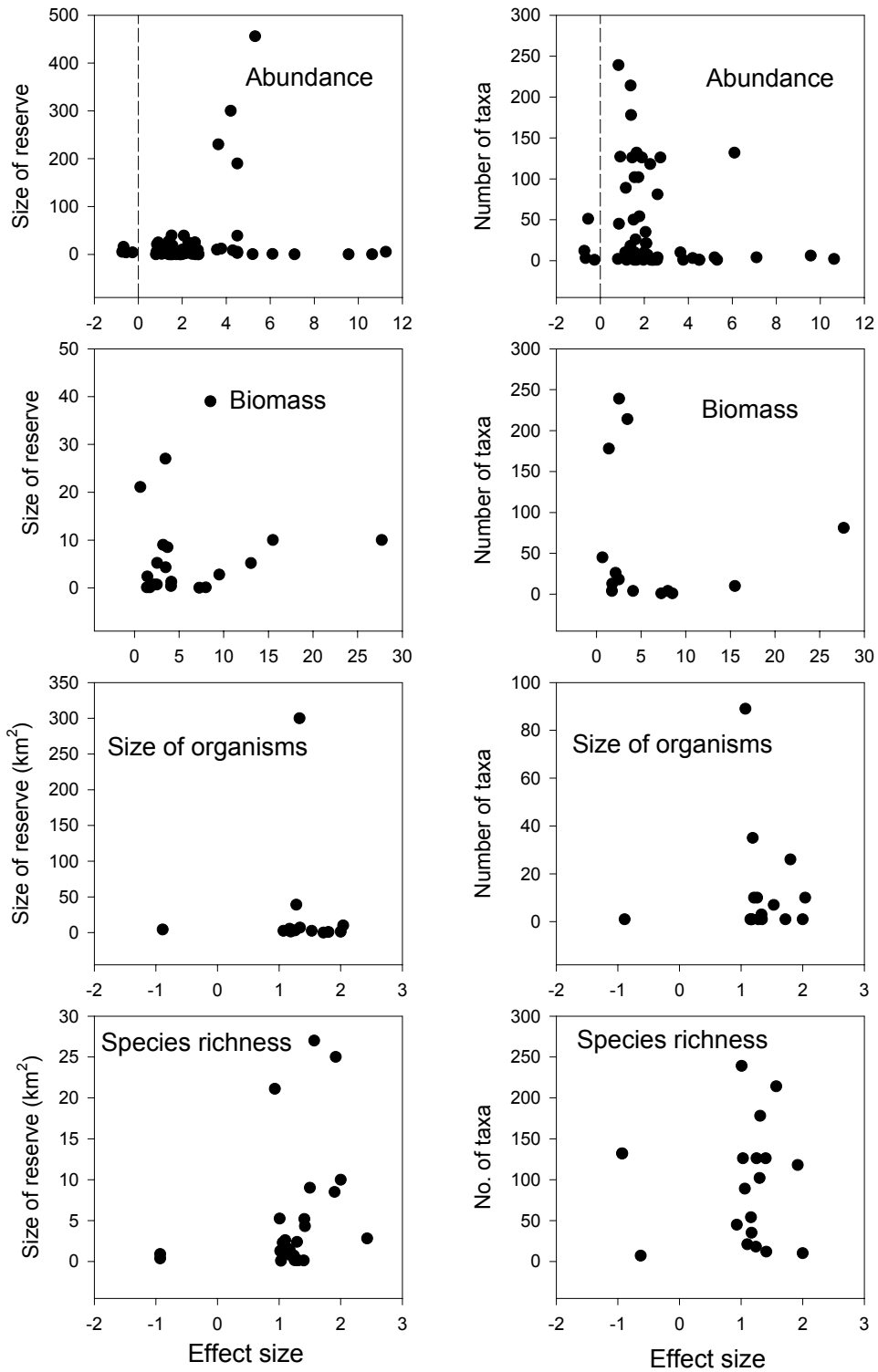
### **3.4 Trophic cascades**

The most interesting results from long-term studies in marine reserves have been those indicating broadscale habitat changes (Babcock et al. 1999, Shears & Babcock 2002, 2003) rather than population studies. Declines in abundance of some species are clearly a possible outcome of increasing the abundances of others. An important consideration in clarifying these ecological processes is allowing manipulative investigations to be carried out. Exclusion of predators, or re-establishing grazer populations that are temporarily protected from predators within reserves, would clarify our understanding of the strength of biological interactions.

Recently Department of Conservation has been funding studies to map marine reserves in varying ways. Spatially-referenced video data provide an opportunity to archive information regarding what species are present, so that if species become of interest in an unanticipated way, it is possible to revisit sites. I suggest that Department of Conservation and institutions researching in marine reserves investigate archiving spatially-referenced video data. Basic maps of bathymetry and sidescan

maps of reefs are a useful tool to start a marine reserve investigation from and may also form the basis for habitat-stratified sampling (e.g. McCormick & Choat 1987).

### Halpern (2003) data



**Figure 1. Plots of effect size vs size of reserve (left column) and number of species included in analysis (right column) from Halpern (2003). Each row represents a different measure of individual or assemblage response.**

### 3.5 Quality of evidence for reserve effects

Russ (2002) outlines a ‘definitive experiment’ to detect a marine reserve effect. It comprises the following information:

- a) data on all relevant variables before and after protection, in replicated pairs of fished and protected locations;
- b) factoring out the confounding effects of habitat and larval supply differences between reserve and fished sites;
- c) including replicate sites within reserve and fished areas;
- d) measuring fishing mortality in reserve and fished locations before and after reserves are established, and over time;
- e) carrying out the experiment on a time scale of 5-20 years;
- f) replicating the experiment regionally to ensure the generality of the result;
- g) measurement of movement patterns across a gradient of reserve / fished sites before and after the reserves have been established; and
- h) measuring catch and catch per unit effort close to and far away from reserves, before and after they are established.

Such a study has not been undertaken and would be difficult and expensive. For the Department of Conservation to have a sound database of scientific support for its marine reserve proposals, it needs to consider supporting studies capable of providing all of the above information.

Measures of fishing effort before and after marine reserve establishment could be made relatively cheaply, and would greatly enhance the interpretation of possible reserve effects. Because reserves are usually compared to nearby areas, if the fishing effort from the reserve is displaced into nearby areas, there may be a decline in the abundance and size of target species there. Simple comparisons of reserve and fished areas would then detect effects of the additional fishing effort on the population outside the reserve, rather than lack of effort having effects inside the reserve. This further emphasises the usefulness of pre-reserve data.

The quality of evidence regarding marine reserve effects internationally has recently been questioned by Willis et al. (in press). They found only a few studies in the international literature, and cited only one New Zealand example (Willis et al. 2003), that could clearly demonstrate reserve effects on abundance of greater than 100% (i.e. twice as many fish inside the reserve as outside). There are two issues here; one is the strength of the response, and the other is the ability to demonstrate it with sampling. It might be possible that some species in marine reserves only exhibit small effects (e.g. abundance increases of 20% or less) because of natural variability in abundance within reserves, or frequent movements beyond reserve boundaries. This does not preclude them having useful outcomes, or render the marine reserve less adequate at preserving biodiversity. A related point, is how big a difference is "important"?. The data presentation approach adopted by Shears and Willis in their recent publications is exemplary in that they provide estimates, with confidence intervals, of the magnitude of difference between reserve and non-reserve sites. Because confidence intervals narrow with increased numbers of samples, statistical differences can be shown, for example if the confidence interval does not include 0, then there is a statistical difference. However, the ability, or inability, to demonstrate a statistical difference should not preclude a conclusion that an important effect occurs.

Willis et al. (in press) also note that few marine reserves have long pre-reservation sampling. As noted above, this suggests that if the Department of Conservation wishes to have clear scientific evidence of change at its marine reserve sites it will have to commit to long-term studies, and—even more difficult—find ways of funding studies at marine reserves before they are established. The use of video-based, rather than diver-based, data might allow cheaper surveys to be carried out, because they may require fewer or less-skilled personnel. Simply collecting video data, but not analysing it until a proposal went forward for public submission, would also save funds. The collection of video data could be done by the department's field staff, or by the supporters of the reserve at the reserve planning stage. However, it does not solve the problem of how to sample fish in areas where visibility is very poor. Traps may enable fish to be released after capture, but are often species-selective, and line fishing is also probably species selective.

### **3.6 Dispersal information**

There is considerable interest in establishing how many larvae disperse from marine reserves (e.g. Palumbi et al. 2003). Benefits of marine reserves will be much clearer if increased export of larvae from reserves occurs. As yet, studies of dispersal of adults have been limited in marine reserves (but see MacDiarmid et al. 1991, Cole et al.

2000, Kelly 2001, Willis et al. 2001) and there is little or no information regarding dispersal of larvae. Until more genetic studies are carried out on New Zealand marine species, this is likely to be an unknown.

## 4 Conclusions

There is abundant evidence that some marine reserves have positive effects on populations of marine organisms—there are more organisms in them, they are bigger etc. The evidence for marine reserve effects could, however, be strengthened by having (a) sampling before marine reserves are established, and (b) measures of fishing effort. However, the area from which that information is drawn is a small subset of New Zealand’s overall biodiversity, and effects of marine reserves elsewhere may be quite different. Some marine reserves, which were originally established because the areas were so special (e.g. Kermadec Islands) may not demonstrate large effects of protection at all.

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## 6 Appendix

**Table A.1 Summary of information on ecological effects of marine reserves in New Zealand. See text for further details.**

Category of effect	Species or assemblage studied	Summary of results	Source
Behaviour			
Response to divers			
	Snapper and blue cod	Snapper approached divers and allowed divers to approach them closer at sites near the centre of CROPMR than at edge sites.	Cole 1994
Dispersal within and beyond reserve	Snapper	Unquantified behavioural changes within CROPMR vs adjacent, fished areas.	Cole et al. 1990
	Snapper	Individual reef-associated fish within CROPMR moved 100s m.	Willis et al. 1998
	Blue cod	Greater dispersal of tagged fish within LIKMR relative to adjacent, fished sites (small sample size).	Cole et al. 2000
	Snapper	Individual fish within CROPMR moved 100s m over ca 4 hr.	O'Dor et al. 2001
	Snapper	Batch and individually tagged fish remained near their tagging sites for periods of up to 4 years.	Willis et al. 2001
	Spiny lobsters	Lobsters tagged inside CROPMR and TMP later found outside reserves (movements into reserves of lobsters tagged outside were not tested).	Kelly 2001
	Spiny lobsters	21% of lobsters tagged within CROPMR remained on same reef for 1-8 yr. 20% of tagged lobsters crossed reserve boundary. Differences in movements among sexes, but larger individuals of both sexes moved less.	Kelly et al. 2002 Kelly & MacDiarmid 2003

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Abundance (continued)			
	Red moki	Population density 2.3 times higher inside reserve than on adjacent, fished areas (sampling stratified by habitat).	McCormick & Choat 1987
	Planktivorous fish	Study of distribution patterns in northeastern New Zealand included CROPMR and PKIMR but no specific comparisons of patterns inside and outside the reserves.	Kingsford 1989
	Snapper, goatfish, spotty, blue cod, leatherjacket	Only red moki showed a clear increase in abundance in a review of data from CROPMR covering 1976-1988.	Cole et al. 1990
	Goatfish, hiwihiwi, red moki	Comparison of 5 fixed sites in broken rock habitats in CROPMR, sampled in 1978 and 1988, showed decreased abundances of goatfish at 2 sites, hiwihiwi at 4 sites, and red moki at 1 site. Note that differences in observers between the 2 times of sampling may confound these observations.	Cole et al. 1990
	Snapper	Comparison of 5 fixed sites in flat rock habitats in CROPMR, sampled in 1978 and 1988, showed decreased abundances.	Cole et al. 1990
	Sea urchins, spiny lobsters	Abundances of lobsters were higher in CROPMR than adjacent, fished sites but those of sea urchins were not.	Cole et al. 1990

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Abundance (continued)			
	Snapper, leatherjacket, butterfish, red moki, parore	Habitat-stratified comparison between CROPMR and adjacent, fished sites showed: <ul style="list-style-type: none"> <li>• In shallow broken rock habitat snapper, leatherjacket, butterfish and red moki were more abundant inside reserve and parore less abundant</li> <li>• In rock flats habitat, red moki were more abundant inside reserve</li> <li>• In kelp forest habitat, snapper, blue cod and red moki were more abundant inside reserve and goatfish less abundant</li> <li>• More small snapper outside the reserve.</li> </ul>	Cole et al. 1990 Willis et al. 2003
	Spiny lobsters	Higher population densities within CROPMR and PKIMR than in five adjacent, fished sites.	MacDiarmid & Breen 1993
	Snapper, blue cod, red moki	Gradients of abundance within CROPMR for snapper and blue cod, but not red moki.	Cole 1994 Willis et al. 2000
	Snapper	Snapper 6-9 times more abundant in CROPMR than in adjacent, fished sites.	Babcock et al. 1999
	Spiny lobsters	Lobsters 1.6-3.7 times more abundant in CROPMR than in adjacent, fished sites.	Babcock et al. 1999

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Abundance (continued)			
	Snapper, blue cod	Snapper 2.6 times and blue cod 2.4 times more abundant inside TWAHMR than in adjacent, fished site, as estimated by BUV. Divers estimated 4.2 times as many blue cod in the reserve.	Willis & Babcock 2000
	Snapper, blue cod	Higher abundances of both species at centre of CROPMR, and twice as many snapper in the reserve compared to adjacent, fished areas.	Willis et al. 2000
	Spiny lobsters	Estimated annual rates of increase in population density following designation of reserve of 3.9% for sites in <10 m water depth and 9.5% for sites >10 m.	Kelly et al. 2000
	Blue cod	Higher population density inside LIKMR than at adjacent, fished sites.	Davidson 2001
	Spiny lobsters	Abundances 2.8 times higher inside TIMR than adjacent, fished areas. Large, reproductive males 10 times more abundant inside. Estimated annual rate of population increase 4.4%, vs 2.9% decrease outside.	Davidson 2001
	Snapper	Abundances of all individuals and of adults were 2.5, 4.2 and 2.1 times as abundant inside CROPMR, TWAHMR and TMP, respectively relative to adjacent, fished areas. Patterns inconsistent for juveniles.	Willis et al. 2003



**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Abundance (continued)			
	Snapper	Abundances higher in CROPMR than at adjacent, fished sites.	Cole et al. submitted
	Blue cod	Abundances similar inside LIKMR and at adjacent, fished sites.	Cole et al. submitted
	Snapper, blue cod, blue maomao, koheru, pink maomao, orange wrasse, scorpion fish	Abundances of snapper higher in PKIMR than at fished sites, numbers of blue cod, blue maomao, koheru, pink maomao, orange wrasse and scorpion fish inside the reserve increased over time, and 8 other species decreased inside the reserve over time (only one species decreased in abundance at the fished sites).	Denny et al. in prep.
	Blue cod	Meta-analysis of 5 studies showed that higher abundances inside reserves were more marked in older reserves, but effects of size and latitude of the reserve were weak.	Pande et al. unpubl.
	Spiny lobsters	Meta-analysis of 10 studies showed that higher abundances inside reserves were more marked in older and more northerly reserves but size of reserve had little effect.	Pande et al. unpubl.

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Size/biomass			
	Red moki	62% of fish were larger than 300 mm inside CROPMR compared with 38% in adjacent, fished sites.	McCormick & Choat 1987
	Snapper	More large fish seen in CROPMR than at adjacent, fished sites.	Cole et al. 1990
	Spiny lobsters	Larger individuals within CROPMR than at adjacent, fished sites. No differences between sites inside and outside PKIMR.	MacDiarmid & Breen 1993
	Snapper, blue cod	More large fish in central part of CROPMR than towards edges.	Cole 1994
	Sea urchins	Larger individuals within CROPMR than at adjacent, fished sites, but no differences in comparisons of TMP with Kawau Island or PKIMR with Mokohinau Islands.	Cole & Keuskamp 1998
	Carnivorous fish species	Larger individuals present within CROPMR than at adjacent, fished sites.	Cole & Keuskamp 1998
	Snapper, blue cod	Snapper ca 70 mm larger and blue cod ca 100 mm larger inside TWAHMR than at adjacent, fished sites.	Willis & Babcock 2000
	Snapper, blue cod	Snapper ca 100 mm larger and blue cod ca 40 mm larger inside CROPMR than at adjacent, fished sites.	Willis et al. 2000

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Size/biomass (continued)			
	Spiny lobsters	Biomass increased 5.4% per annum at shallow sites and 10.9% at deep sites inside 4 reserves of varying age in northeastern New Zealand. Egg production increased by 4.8% and 9.1% at shallow and deep sites, respectively.	Kelly et al. 2000
	Blue cod	Average size larger inside LIKMR than at adjacent, fished sites but this pattern took several years to become apparent.	Davidson 2001
	Spiny lobsters	Average carapace length was 19 mm larger at shallow sites and 28 mm larger at deep sites inside TIMR than at adjacent, fished sites.	Davidson et al. 2002
	Snapper	Biomass in CROPMR, TWAHMR and TMP 4-12 larger than at adjacent, fished sites. Mean differences were 60-144 mm for all fish and 24-104 for fish larger than MLS. Ratios for egg production were 7-23.	Willis et al. 2003
	Blue cod	Fish inside LIKMR were larger than at nearby, fished sites. Sample sizes too small to test equivalent differences at CROPMR and TIMR.	Cole et al. submitted

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Size/biomass (continued)			
	Blue cod	Meta-analysis of data from 5 studies did not identify clear effects of age and size of reserve on size of fish, but southern reserves appeared to show larger effects than northern ones (note that only one northern reserve was included in the analysis).	Pande et al. unpubl.
	Spiny lobsters	Meta-analysis of data from 10 studies indicated that older, more northerly reserves had a larger effect on sizes of individuals, but size or reserve did not have an effect.	Pande et al. unpubl.
Assemblage structure and composition			
	Fish assemblages	Habitat-stratified comparisons showed greater species richness inside CROPMPR than at adjacent, fished sites (though this could have been an effect of locality rather than the presence of the reserve).	Cole et al. 1990
	Macroalgal assemblages	Suppressed cover of coralline flats and greater cover of kelp forest inside CROPMPR relative to adjacent, fished sites.	Babcock et al. 1999
	Macroalgal assemblages	More turfs and less Crustose corallines inside CROPMPR than at adjacent, fished sites.	Shears & Babcock 2002

**Table A.1 Continued.**

Category of effect	Species or assemblage studied	Summary of results	Source
Assemblage structure and composition (continued)			
	Macroalgal assemblages	Mixed algal assemblages were 3.6 times and kelp forest 2.7 times more likely to occur inside CROPMR than at adjacent, fished sites.	Shears & Babcock 2003
	Fish assemblages	Numbers of species were not consistently different between CROPMR, LIKMR or TIMR and adjacent, fished sites.	Cole et al. submitted