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Relative density of blue cod (*Parapercis colias*) in Milford and Doubtful Sounds in response to spatial management

New Zealand Fisheries Assessment Report 2012/36

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Baited underwater video surveys within designated management zones of Milford Sound and the Doubtful Sound complex found low numbers of blue cod and tarakihi. Densities of both species tended to be higher at fiord entrances and on the open coast than inside fiords despite these areas being open to fishing.

Low abundance of blue cod meant that the statistical power to detect relative density differences between marine reserve and closed areas was poor. The low numbers of blue cod in Milford Sound was surprising, as a marine reserve on the southern face of the fiord has been in place since 1993. The result suggests that either the comparison was confounded by other factors (such as habitat differences between the north and south faces of the fiord), or that the population has reached a natural density for that habitat. Because colonisation appears to be based on adult immigration (few small blue cod were found inside the fiords), fishing in the currently closed areas would be likely to result in rapid depletion of the small biomass.

While the sampling method was effective, the variability in counts brought about by low numbers of fish (*e.g.*, 31 of 78 stations showed no blue cod at all and a further 22 stations showed only one blue cod) indicates that comparisons of relative densities of fish among different management zones are not robust. These results are similar to previous line fishing surveys for blue cod in Milford and Doubtful sounds. The overall conclusion is therefore that blue cod are not abundant at any locations inside Milford Sound or the Doubtful Sound complex regardless of marine reserve or temporary fishing closure designations.

1 INTRODUCTION

Blue cod (*Parapercis colias*) are highly sought after by a wide range of New Zealand fishers and are particularly important to Southland fishers. Milford and Doubtful Sounds have been closed to recreational fishing for blue cod since 30 June 2005 in addition to the existing prohibition on commercial fishing throughout fiord waters. Milford Sound has one marine reserve (the northern face of the fiord) established in 1993. Doubtful Sound has three marine reserves, one of which (The Gut) was implemented in 1993, the other two (Elizabeth Island and Gaer Arm) were established at the same time as fishing was banned in the whole of Doubtful Sound (2005). The closures resulted from concerns about localised depletion of blue cod due to fishing pressure. The closures were for two years initially, but were extended for a further two years in 2007, then indefinitely in 2009 to provide an opportunity for blue cod stocks to recover.

To inform any decision about reopening the areas and any fishery management measures (bag limits, method restrictions, etc) that could apply, monitoring of the relative abundance in Milford and Doubtful Sounds has been carried out each summer since 2006. This monitoring was initially based on hook-and-line angling. No trend in abundance (as measured by catch-per-unit-effort) in either fiord was detected, although both areas had greater numbers of large cod in closed areas. However, the final report from that programme suggested that, due to the low sample size, existing survey methodology and design were insufficient to determine the rate of recovery in the closed areas (Key 2010). The Ministry of Fisheries (now Ministry for Primary Industries) considered that with line fishing, more frequent sampling would be required for a more robust conclusion. This study used a fishery independent method in an attempt to overcome the low sample size and hook selectivity issues that occur using hook-and-line angling as a sampling tool.

Site selection within Milford and Doubtful Sounds was compatible with previous line fishing surveys within the constraints of a balanced survey design. Previous surveys utilising hook-and-line methods lacked controls for fishing. No fished areas were included in the surveys to determine whether trends observed in protected areas were a result of protection, or a reflection of larger regional population trends. A previous survey that did utilise non-reserve control sites surveyed blue cod in six Fiordland marine reserves using underwater visual census (UVC), and found no difference in blue cod density between marine reserves and non-reserve areas (Willis et al. 2009).

Baited underwater video (BUV) was developed to sample the relative density of snapper and blue cod in marine reserves (Willis & Babcock 2000, Willis et al. 2000). As with all video sampling techniques, it is a non-extractive sampling method, but differs in that a fixed camera is deployed that records fish responding to enclosed bait. In this respect it operates in the same way as a fish pot, but is not subject to capture biases associated with the gear because the video provides a continuous record of fish responding to the bait. Lengths of blue cod can be measured with an accuracy of less than 20 mm from digitised images calibrated by markings on the base frame (Willis & Babcock 2000). BUV estimates of relative abundance and size have been demonstrated to have a strong linear relationship (Pearson ρ=0.90) with UVC counts of blue cod (Willis & Babcock 2000) and the method has been successfully used for marine reserve monitoring surveys of blue cod and snapper for over 10 years (Willis et al. 2003, Willis & Millar 2005). A modified system was successfully deployed in Dusky and Doubtful Sounds as part of a deep reef survey for the Department of Conservation in 2009 (Handley et al. 2010).

The overall objective of this project was to monitor changes in size and abundance of blue cod and other finfish in differently managed areas of Doubtful and Milford Sounds. This included determining changes in size and abundance of blue cod populations in Milford Sound by comparing catch rates and size composition of fish from within the longstanding Marine Reserve, which has been closed to fishing since 1993, with those from an area that has been closed to blue cod fishing for a shorter period of time.

This report presents the results of the 2011 BUV surveys of blue cod in Milford and Doubtful Sounds. Relative density and size estimates for tarakihi (*Nemadactylus macropterus*) were included as an opportunistic analysis. During the tender process, the Southern Inshore Working Group (SIWG) elected to omit Specific Objective 2 from this project, and tagging studies were therefore not undertaken.

2 METHODS

Baited underwater video

Configuration of the BUV consists of a metal stand supporting a camera that points vertically downward at an enclosed bait container (Willis & Babcock 2000). Surveys in northern New Zealand have used pilchard *Sardinops neopilchardus* as the bait, but the viscera of paua *Haliotis iris* are very effective for attracting blue cod and were used in this study. The base of the stand is marked with calibration points (Figure 1), so that frame grabs can be calibrated and the lengths of individual fish measured using image analysis software. While earlier versions of BUV utilised a camera cabled to a monitor and recorder aboard an anchored vessel (Willis & Babcock 2000, Willis et al. 2000), the units used in this project employed Sony HDR-XR350 handycams with a 160 GB hard drive in custom-built housings. Use of self-contained handycams allowed the apparatus to be remotely deployed and multiple replicate deployments to be made simultaneously. Thirty minute deployments are usually sufficient to obtain precise density estimates (Willis & Babcock 2000), so cameras were not retrieved until at least 30 min had passed after the BUV was released.

In areas where the terrain was steep and the reef biota very fragile, BUV deployments were made with the aid of a second positioning camera (Splashcam) attached to the BUV buoy line, and cabled to a surface video monitor to manoeuvre the BUV unit into a suitable position before release. Red LED lighting systems were fitted to the BUV to ensure a usable image in low light conditions. Red light (rather than unfiltered white light) is believed to cause minimal disruption to fish behaviour (Widder et al. 2005). Two remotely deployed BUV units were used concurrently within different strata so that field sampling was optimised within the time available.

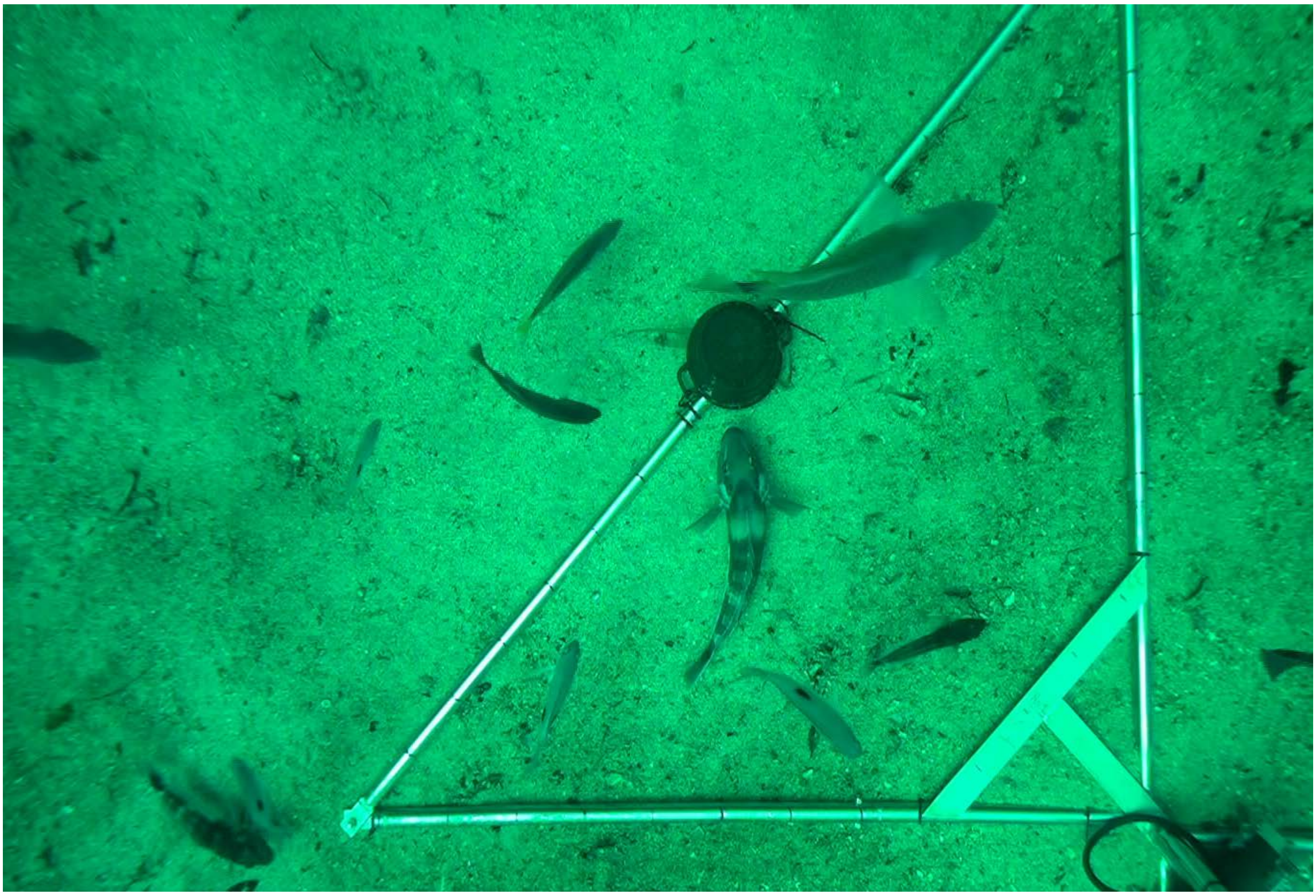

Figure 1: Frame from a BUV sample in Thompson Sound, showing image calibration marks placed at 10 cm intervals around the base of the video stand.

Survey design

The survey used a stratified random approach, with strata defined spatially according to the management measures in place:

1) Marine reserves (reserve)
2) Temporary fishing closures (closed)
3) Areas open to fishing (open)
4) Open coast areas outside the fiords (Outside)

Both fished and unfished areas were included in the sampling design to assess changes in fish density against fisheries management and large scale changes to the fish population. In consultation with the

Ministry of Fisheries, the survey design also included strata at the mouth of the two fiords and on the open coast outside each fiord, as these areas may be source populations for inner-fiord blue cod (Carbines & MacKenzie 2004).

Four BUV stations per stratum were selected randomly along the coastline prior to the survey commencing. The coastline of each stratum was measured in ArcMap (ESRI, Inc.), and divided into 100-m sections, each representing a potential sampling station. Stations were then randomly allocated by selecting four of these sites for each stratum. True randomisation of sampling sites over the entire stratum area was not feasible, because 1) the sheer nature of fiord topography means that most blue cod habitat is close to the coast; 2) the depth of the fiords means that much of the area is beyond the preferred range of blue cod (60 m); and 3) previous line fishing survey sites have been placed close to the shore. Sampling depths were limited to less than 60 m. Given this linear arrangement of a narrow depth contour along the shoreline, no attempt was made to further delineate "blue cod habitat" within the 0–60 m depth contour of each stratum.

Milford Sound was divided into nine strata (Figure 2): three along the north wall (M1, M2, and M3: existing marine reserve), three along the south wall (M4, M5 and M6: closed area), and three open coast strata (M7, M8 and M9, fished, Table 1).

Thirteen strata were included in the survey design of the Doubtful Sound complex (Figure 3). There were three marine reserve strata (D2, D4 and D9), two open strata in in internal waters (D5 and D10), and three outside areas on the open coast (D11, D12 and D13). The remaining five strata (D1, D3, D6, D7 and D8) were placed in closed areas. Due to a sustained period of poor weather during the survey, the open coast strata D12 and D13 could not be sampled. Four deployments were planned per stratum, but on two occasions only three replicates were completed because the BUV unit could not be deployed on a stable surface (Table 1).

Table 1: Summary of the distribution of BUV sampling effort. Four deployments per stratum were planned.

Fiord	Treatment	Stratum	No. stations completed
Milford	Reserve	M1	4
		M2	4
		M3	3
	Closed	M4	4
		M5	3
		M6	4
	Outside	M7	4
		M8	4
		M9	4
Doubtful	Reserve	D2	4
		D4	4
		D9	4
	Closed	D1	4
		D3	4
		D6	4
		D7	4
		D8 (E+W)	4
	Open	D5	4
		D10	4
	Outside	D11	4
		D12	0
		D13	0
Total			78

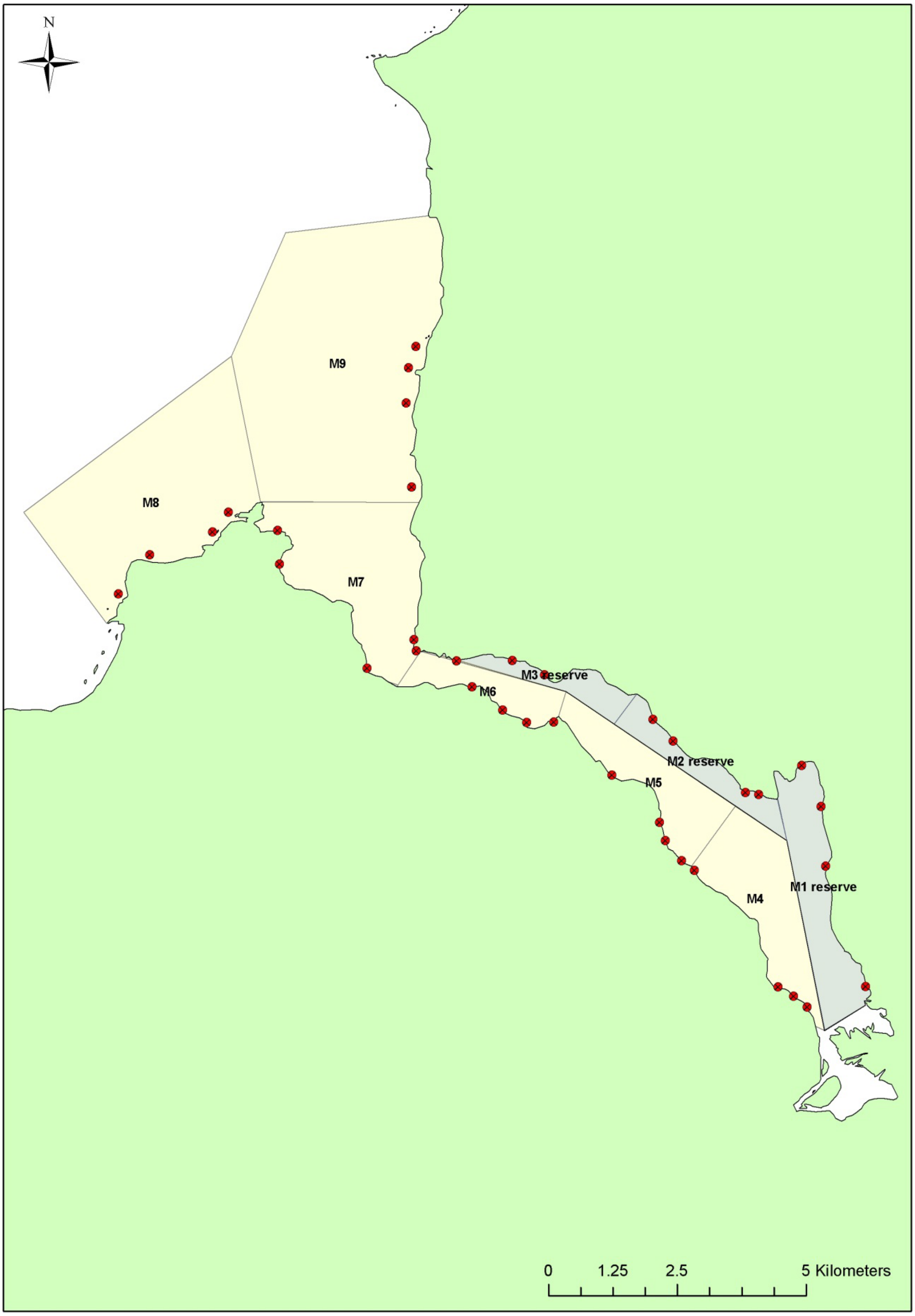

Figure 2:. Survey design for BUV survey of Milford Sound. Dots are intended positions of BUV stations generated randomly within each survey stratum.

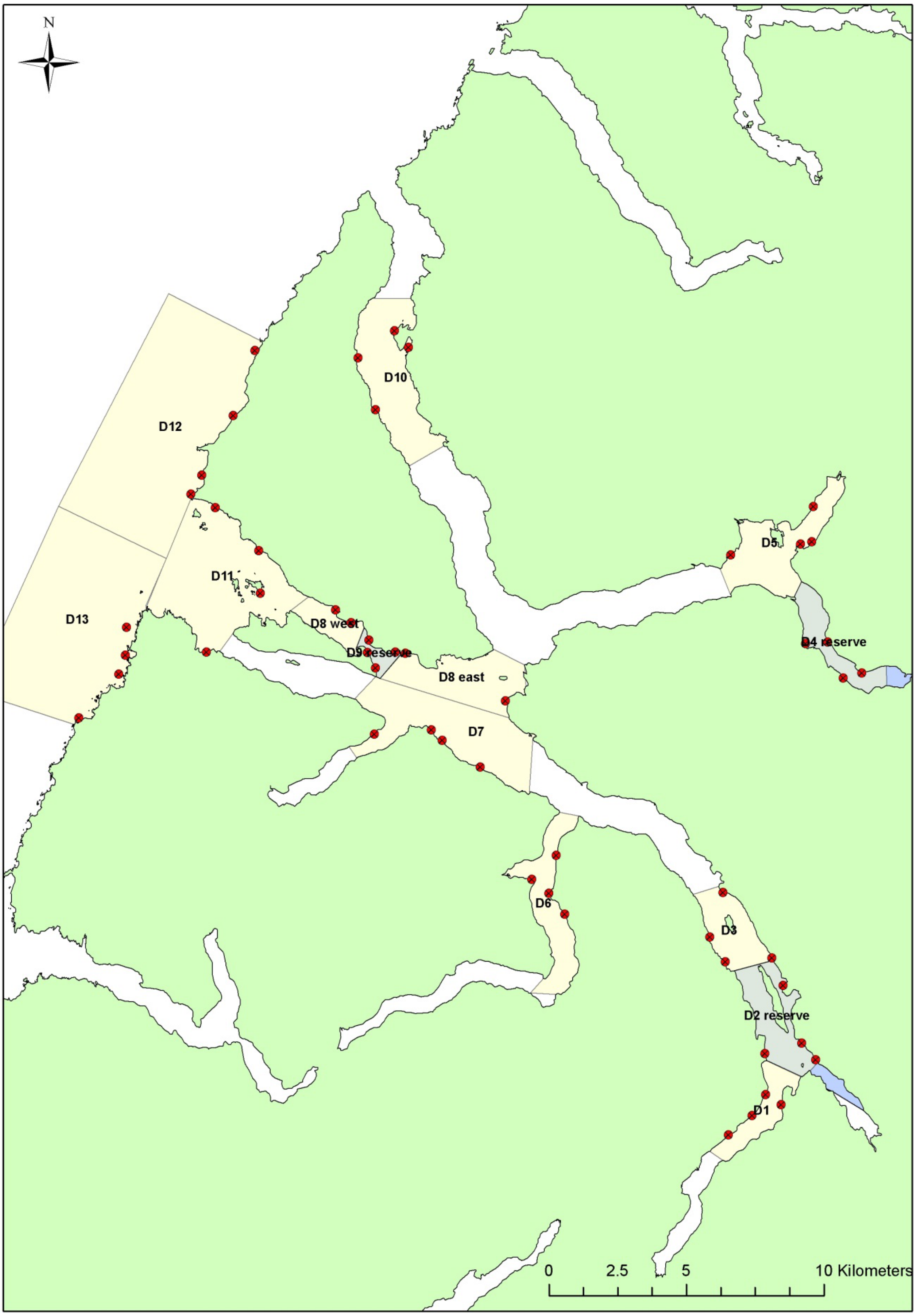

Figure 3: Survey design for BUV survey of Doubtful, Thompson and Bradshaw Sounds. Dots are intended positions of BUV stations generated randomly within each survey stratum.

Video and data analysis

Relative density is expressed from BUV footage as the maximum number of fish of a given species observed at any one time during the 30 minute deployment (usually referred to as MAXno). The value is determined by reviewing the video and determining the video frame with the maximum number of fish present. In that frame, each fish was then sampled for length. After that frame, if any fish left the station, then additional fish arriving at the station were only included in the sample if their size had not been recorded previously during the sample. This prevents a positive bias from fish moving in and out of the camera's field of view, but could generate an underestimate of numbers of fish if a narrow size range of mobile fish was present. Typically, few fish were observed, they usually arrived quickly upon deployment, and did not leave the bait station during the video deployment.

Fish contributing to the MAXno value were measured from digitised images calibrated using a three-point calibration in SigmaScan Pro 5 (Systat 2012). The accuracy of image calibration was checked against marks on the base of the BUV stand and the bait holder dimensions. Since the calibrated plane is at ground level, measurement error can only be an overestimate of fish length. Willis & Babcock (2000) estimated the average overestimate of blue cod total length by this method to be 16.9 ± 2.4 (s.e.) mm. Substratum type was also recorded. Tarakihi were more difficult to measure because they were less in contact with the bottom and therefore not at the same range as the calibration bar for length measurements. This would tend to overestimate their size composition.

Comparisons were made as relative densities observed per 100 m segment sampled, and therefore no scaling to the overall stratum coastline (or total stratum area) was made. All results are presented as the mean per station in each stratum.

Count data of blue cod and tarakihi from BUV were analysed using GLMs (generalised linear models), using a log link and assuming a Poisson distribution for count data (Littell et al. 1996). Such a log-linear model expresses the counts, Y, as

$$Y \sim Poisson(\lambda)$$

where $Poisson(\lambda)$ denotes a Poisson distribution (although possibly overdispersed) with expected value of λ, and $\log(\lambda)$ was modelled as a linear function of the effects. For example, the count of a species at fiord i, and treatment j, was modelled as

$$\log(\lambda_{ij}) = \alpha_i + \beta_j$$

where α, and β denote effects due to location, and management status. The right-hand side of this equation can be modified to include any interactions of interest. A Poisson distribution is generally assumed for count data, although a negative binomial distribution may be used if significant over-dispersion is identified (as indicated by the deviance/df value for each fitted model).

Individual fish weight for blue cod (BCO) and tarakihi (TAR) were estimated from fish length using existing length-weight relationships (with weight (W) in g and total length (L) in cm):

BCO: $W = 0.007825 \times L^{3.1727}$ (Carbines & Beentjes 2003)

TAR: $W = 0.0257 \times L^{2.9868}$ (Stevenson 2006)

Weight was modelled in a similar fashion to counts, but using an identity link and Gaussian distribution for the continuous variable. Fish size distributions are presented as combined, unscaled histograms of fish measured in each treatment area.

Specific objective 3 was addressed by modelling blue cod relative density in marine reserves, closed areas, fished areas in the open coast strata, and inner sound fished areas in Doubtful Sound. There were no fished areas in Milford Sound, so this stratum was omitted from models comparing the two fiords. Power analyses for log-linear models, following a procedure described by Willis et al. (2003), were conducted to determine effective sample sizes for future surveys where significant treatment effects were not found. The use of traditional forms of power analysis assumes homogeneity of variance, which does not apply to count data. For Poisson data the variance equals the mean, but more generally, the data may be overdispersed with $\sigma^2 = \phi\mu$ where ϕ is the overdispersion parameter. Here, the overdispersion parameter was estimated as part of the log-linear model, as deviance/df. If differences between means are expressed as ratios, and $1-\beta$ denotes statistical power (i.e., β=Type II error rate) then β can be obtained as the value having standard-normal quantile z_β given by

$$z_\beta = \frac{\log(k)}{\sqrt{\frac{\phi}{n\mu_1}\frac{k+1}{k}}} - z_{\alpha/2}$$

Here, $k = \mu_2/\mu_1$ is the ratio of the two specified means, with μ_1 taken to be the lower of the two (so that log(k) is greater than 0), n is the sample size in each of the reserve and non-reserve areas, and the quantile $z_{\alpha/2}$ is the value that a standard normal random variable exceeds with probability $\alpha/2$ (e.g., $z_{\alpha/2} = 1.96$ for $\alpha = 0.05$). For derivation of this method, see Willis et al. (2003).

3 RESULTS

Blue cod

Blue cod densities were low inside the fiords. Of the 78 stations, 31 had no blue cod and 22 had only one. Figures 4–7 show the spatial distribution of the number and biomass of blue cod sampled by station in Milford Sound and the Doubtful Sound complex. There was considerable variation among samples, even within sampling strata. Generally numbers diminished and the frequency of zero counts increased towards the head of fiords, and the highest counts and biomass tended to be found in open coast strata. Comparing fiords, the fished 'Outside' strata contained 4.1 times (95% Confidence Limits: 1.84, 9.05) the density of blue cod found in the reserve areas ($\chi^2 = 11.95$, $p = 0.0005$), but only 1.5 times (95% CL 0.72, 3.12) the biomass ($\chi^2 = 0.26$, $p = 0.6108$). The lack of significant difference in biomass reflects the greater size of fish found in the reserves and closed areas inside the fiords (see below).

In fiord habitats, there were generally higher densities of blue cod in Milford Sound compared to Doubtful Sound, but densities were higher in the outside coast stratum at Doubtful Sound than at Milford (Figure 8). This comparison is however based on only one surveyed stratum at Doubtful Sound, since the two more exposed strata at this location could not be surveyed due to poor weather.

Among the four marine reserves in the two fiords, overall reserve densities of blue cod did not differ from that of closed areas, with a Reserve:Closed ratio of 1.3:1 (95% CLs 0.62, 2.64, $\chi^2 = 0.45$, $p = 0.5029$), and a biomass ratio of 1.74:1 (95% CLs 0.82, 3.69, $\chi^2 = 2.07$, $p = 0.1504$). This may not be surprising, since two of the four reserves were implemented concurrently with the fishery closures. The low numbers of fish means that limited conclusions may be drawn from size distributions of blue cod, but it is clear that few small fish (smaller than 25 cm) are found inside the fiords relative to the open coast/fiord entrance areas (Figure 9). The relatively high proportion of small blue cod in "outside" areas explains why mean biomass is not higher than inner fiord areas despite higher fish densities (Figure 8). An example of one of the highest density stations in Milford Sound is shown in Figure 10.

Within individual reserves, densities of blue cod did not differ between marine reserve areas and closed areas at any location except for The Gut, where numbers were 3.5 times (95% CL 0.93, 13.12) higher than at adjacent sites (Table 2). Although differences in counts were not statistically significant (χ^2 = 3.63, p = 0.0567), biomass was 13 times (95% CL 1.54, 106.58) higher in the reserve because of the larger size of the reserve fish (χ^2 = 6.51, p = 0.0107). Ratios for the Gaer Arm reserve were uninformative, because no blue cod were sampled inside the reserve (Table 2). At Milford Sound, blue cod densities and biomass were both similar in reserve and closed areas (Table 2), despite the reserve having been put in place 12 years before the fishing closure.

Table 2: Density and biomass means, ratios (Reserve:Closed) with 95% confidence limits, and results of maximum likelihood tests for the ratios at four Fiordland marine reserves for blue cod *Parapercis colias* numbers and biomass.

Reserve	Reserve mean	Closed mean	Reserve:Closed ratio	Lower 95% CL for ratio	Upper 95% CL for ratio	χ^2	p
Blue cod numbers							
Elizabeth Island	0.67	0.50	1.33	0.22	7.94	0.10	0.7561
Gaer Arm	0.00	0.50	N/A				
The Gut	1.75	0.50	3.50	0.93	13.12	3.63	0.0567
Milford Sound	1.91	2.09	0.91	0.35	2.35	0.04	0.8503
Blue cod biomass							
Elizabeth Island	0.59	0.27	2.15	0.32	14.51	0.58	0.4446
Gaer Arm	0.00	0.20	N/A				
The Gut	1.43	0.11	12.82	1.54	106.58	8.95	0.0028
Milford Sound	1.77	1.61	1.10	0.45	2.66	0.04	0.8340

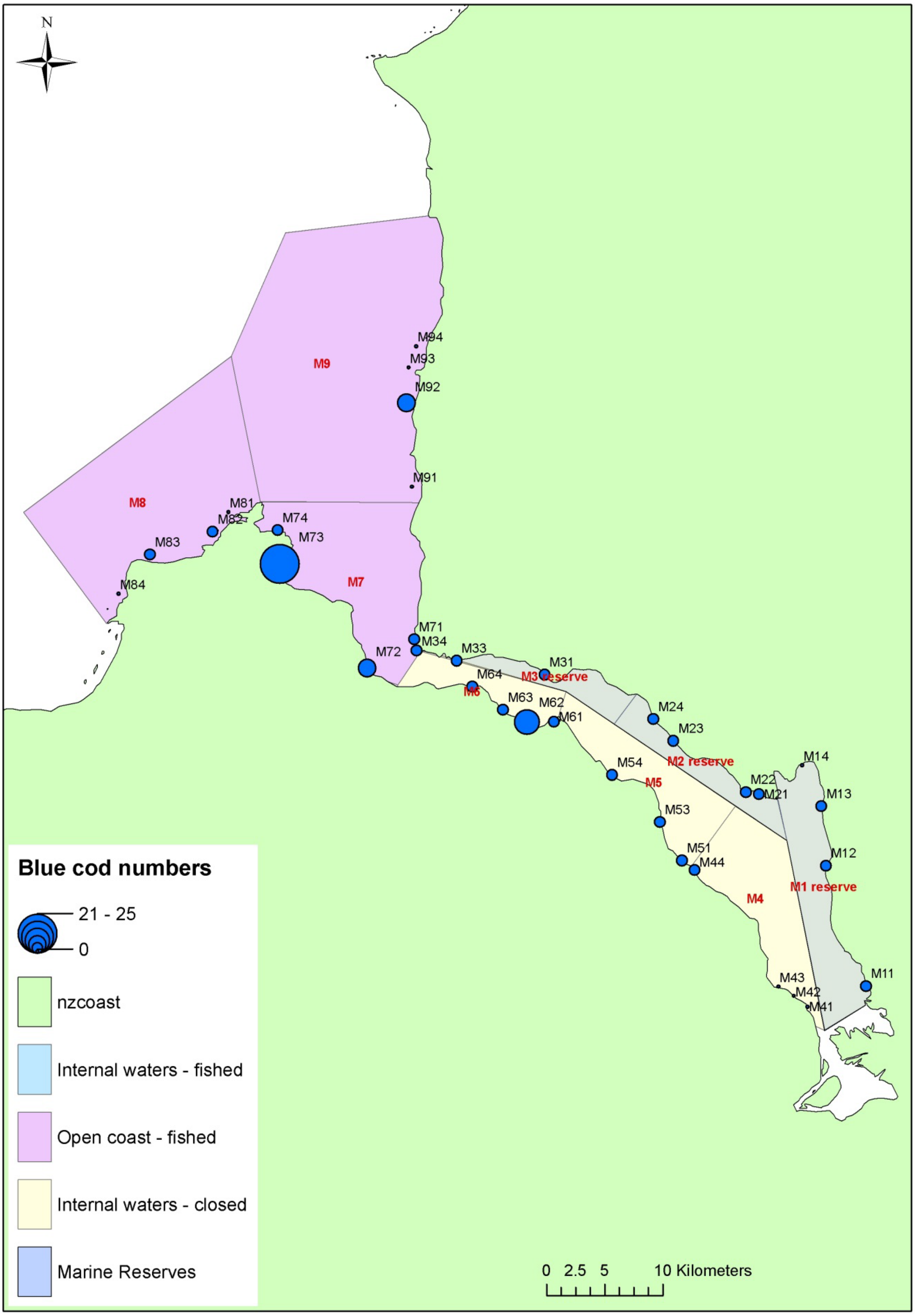

Figure 4: Number of blue cod *Parapercis colias* at each sample site in Milford Sound. The size of the blue circles represents the number of fish observed, and a dot represents a zero count.

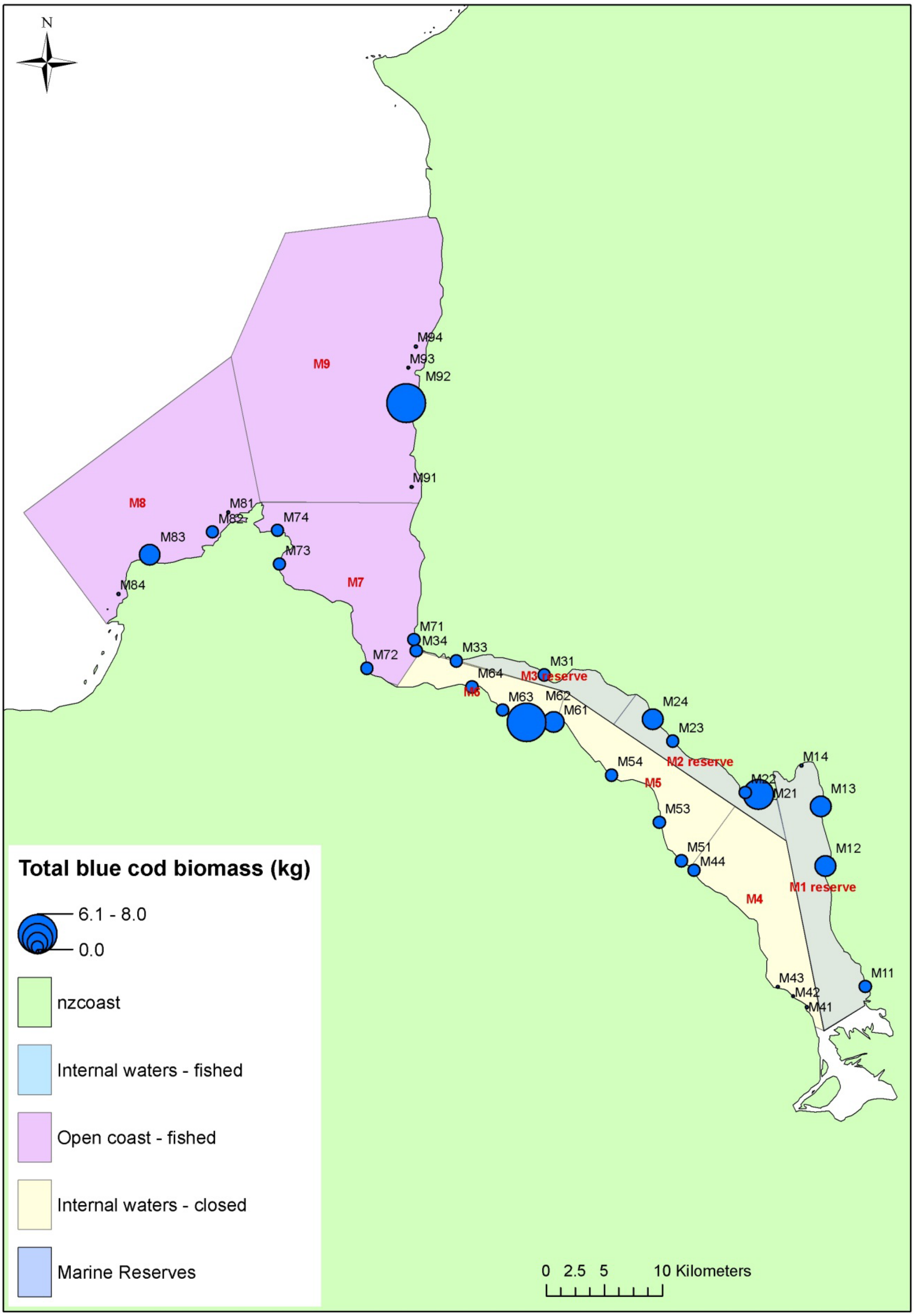

Figure 5: **Biomass of blue cod *Parapercis colias* at each sample site in Milford Sound. The size of the blue circles represents the mass of fish in the sample, and a dot represents a zero weight.**

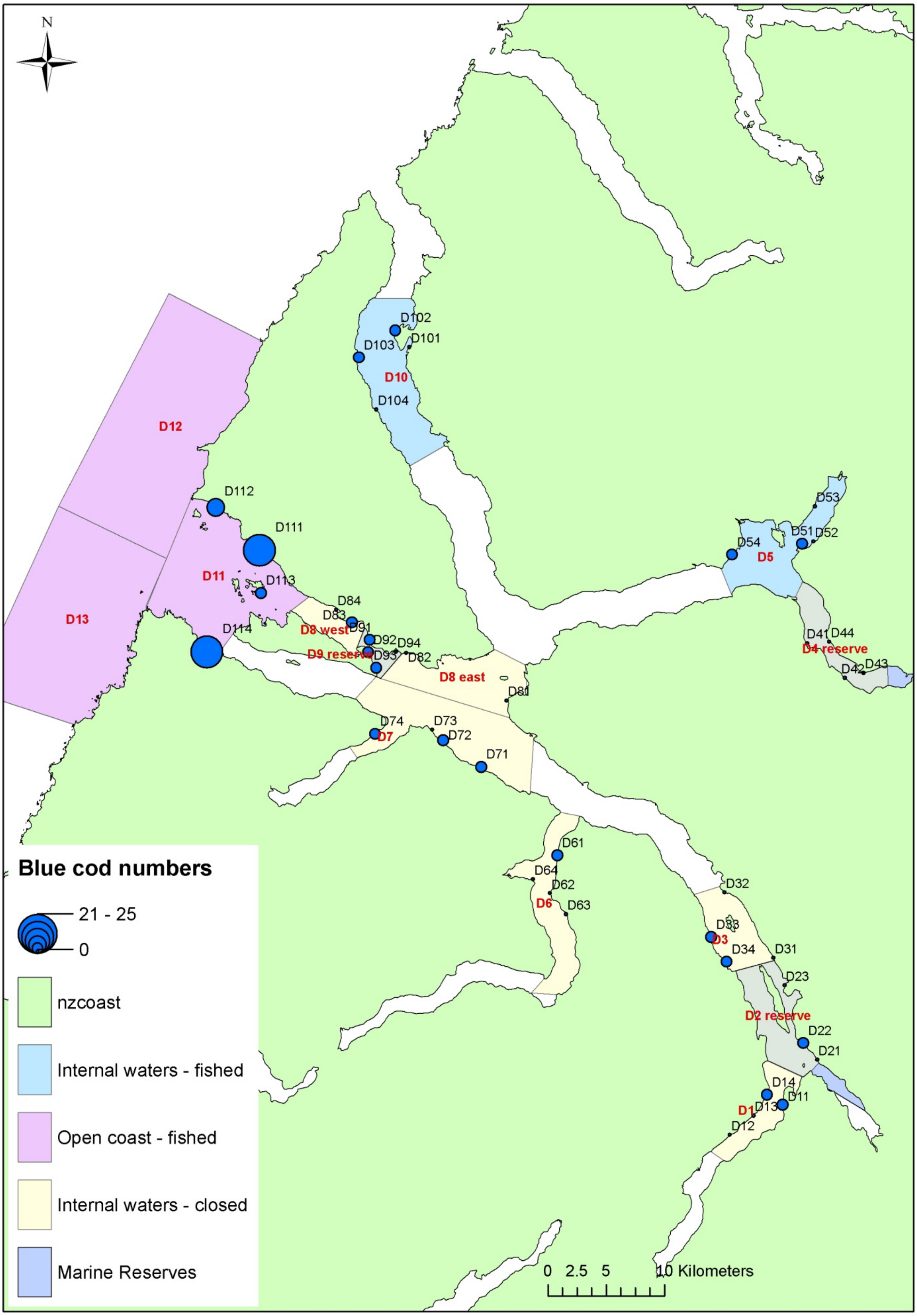

Figure 6: Number of blue cod *Parapercis colias* at each sample site in the Doubtful Sound area, where the size of the blue circles represents the number of fish, and a dot represents a zero count.

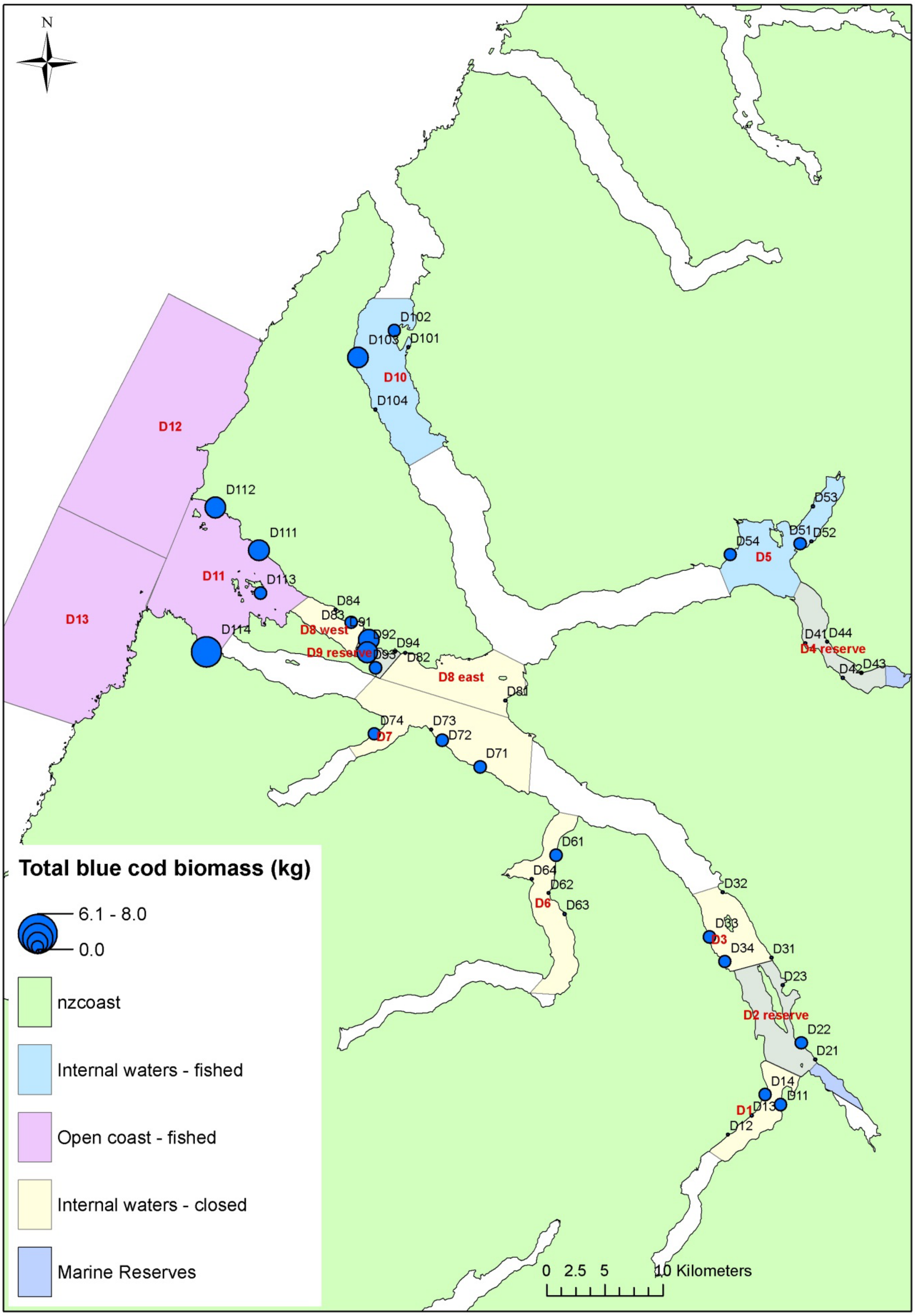

Figure 7: Biomass of blue cod *Parapercis colias* at each sample site in the Doubtful Sound area, where the size of the blue circles represents the mass of fish in a sample, and a dot represents a zero weight.

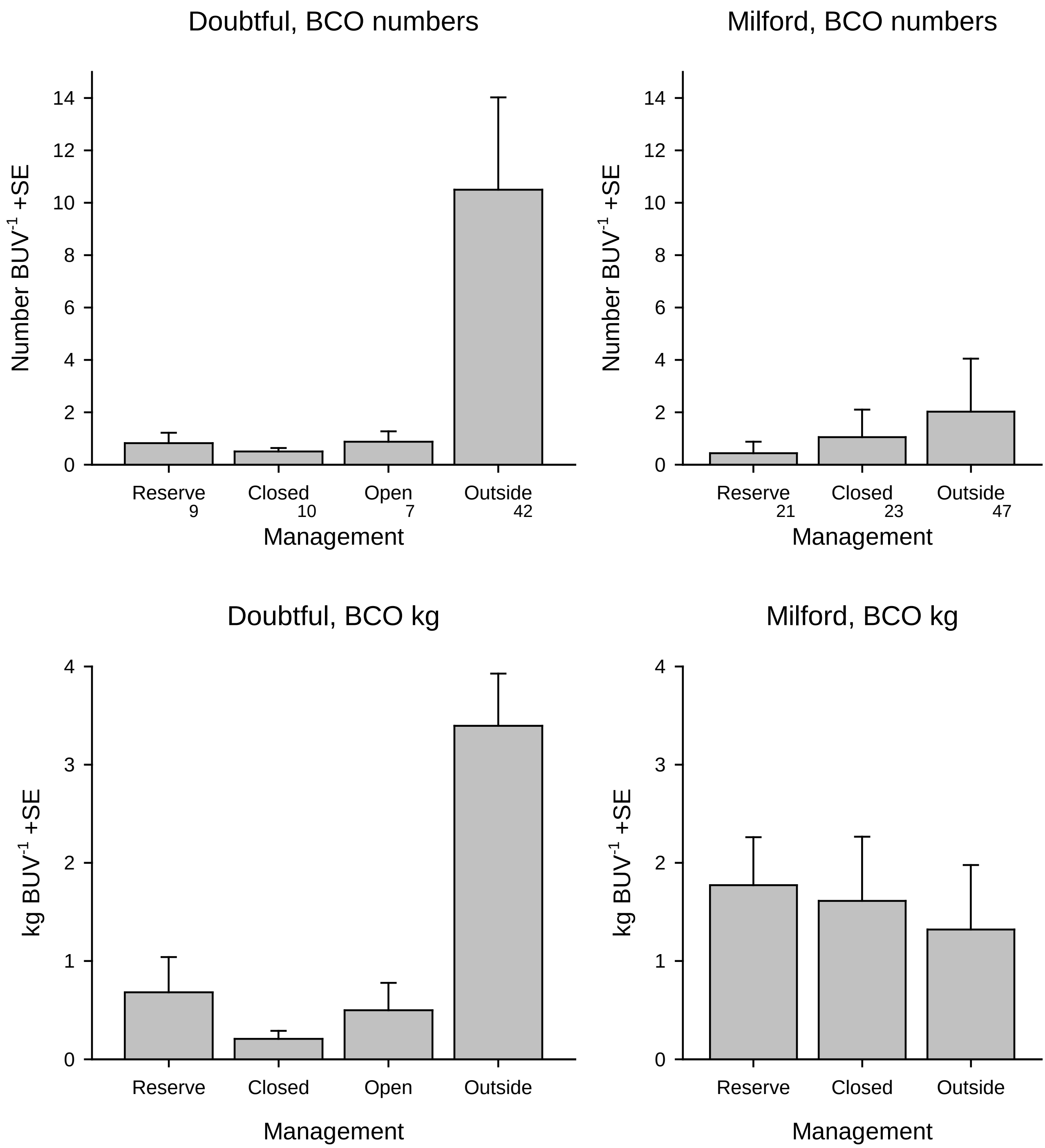

Figure 8: **Relative density and biomass of blue cod *Parapercis colias* in different management zones of the Doubtful Sound complex and Milford Sound. Numbers under management zone labels indicate sample size.**

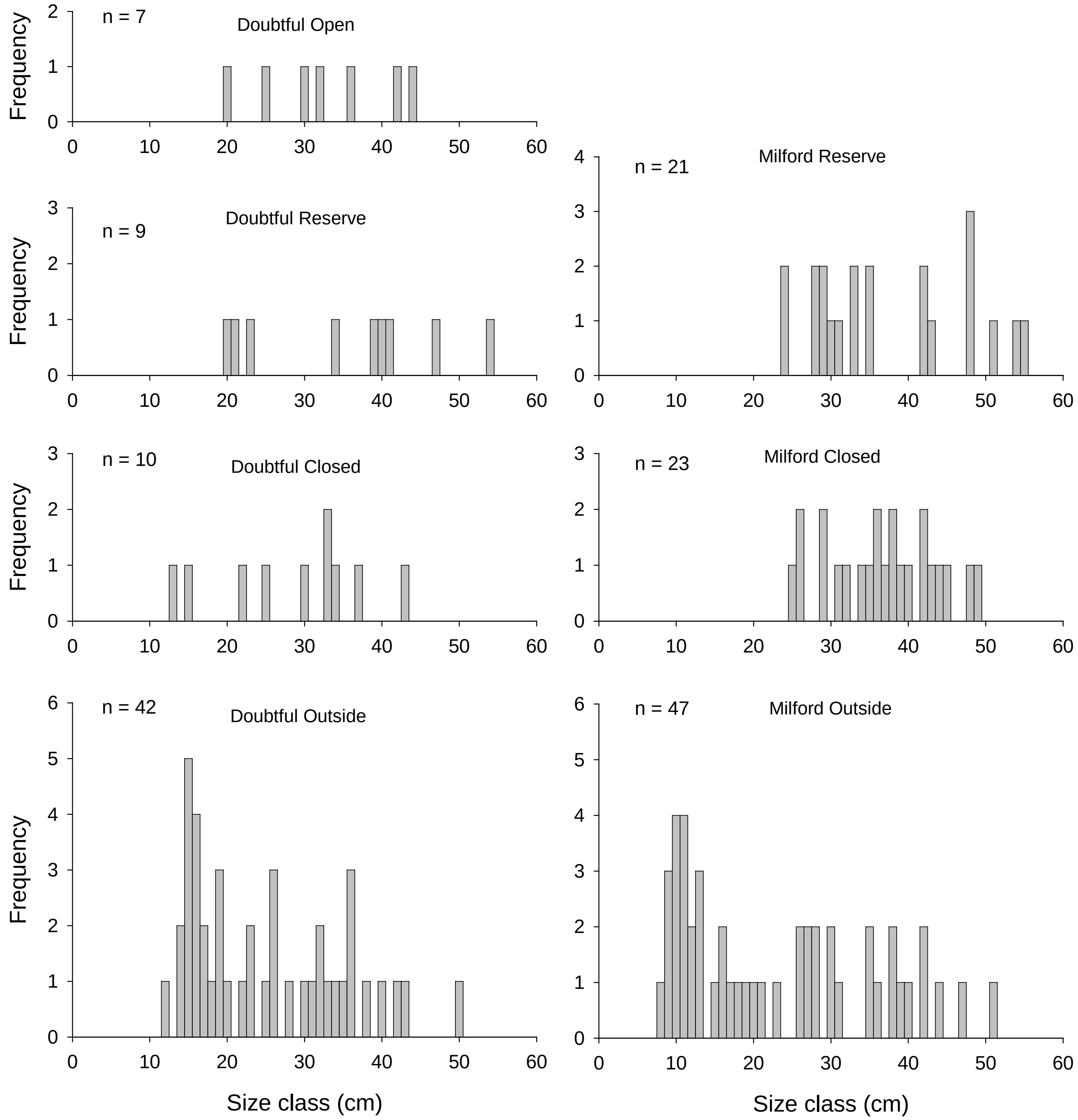

Figure 9: Size frequency of blue cod *Parapercis colias* in different management zones of the Doubtful Sound complex and Milford Sound.

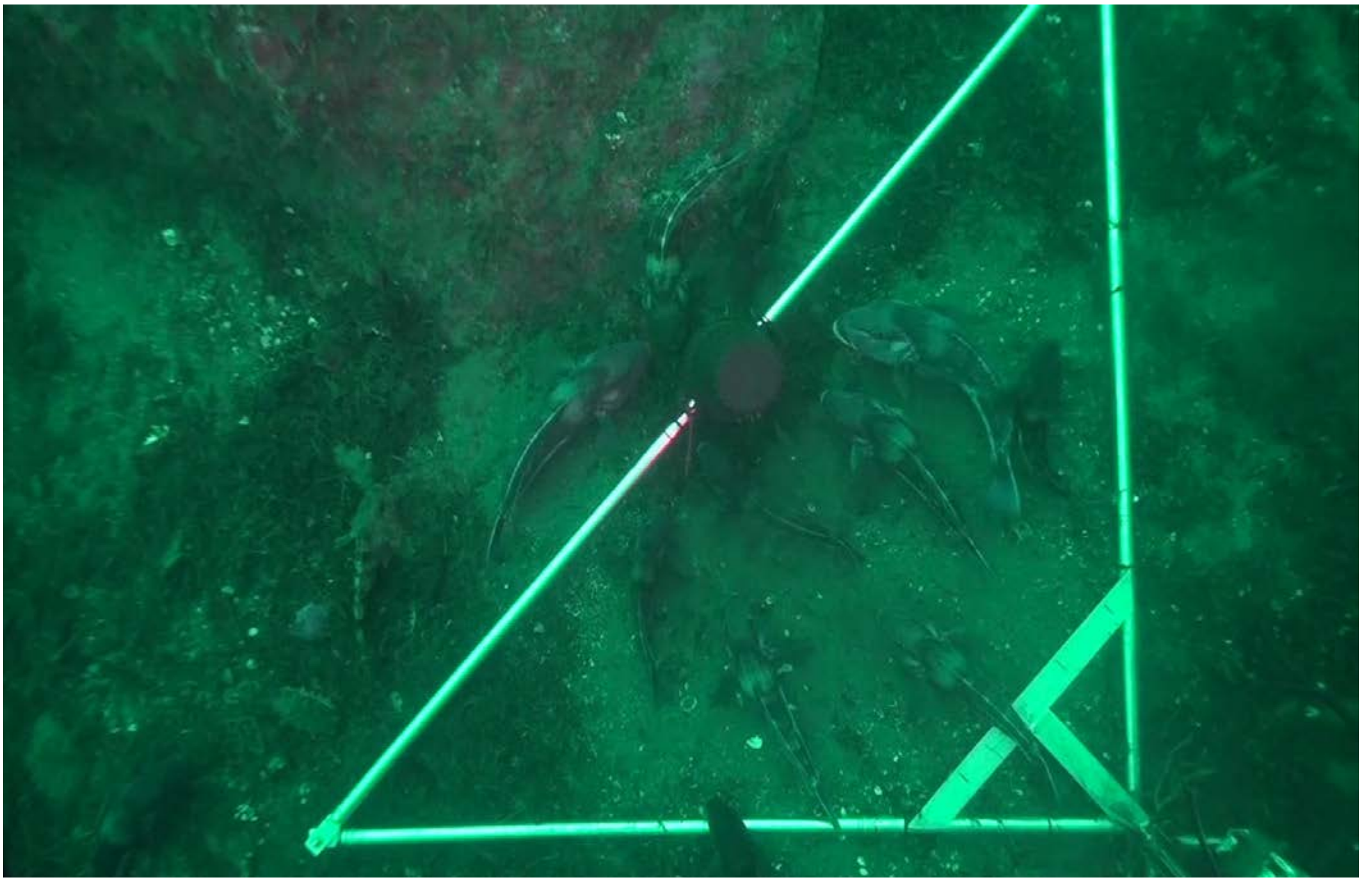

Figure 10: A high density station in Milford Sound (Station M62). Ten blue cod, one sea perch *Helicolenus percoides* and one tarakihi *Nemadactylus macropterus* – head entering shot at bottom centre- are visible.

Power analyses of data from three of the reserves illustrate changes in statistical power with increasing sample size. Conventionally, a criterion for power (1-β) is set at 0.8, meaning that β (the probability of a Type II error occurring), is 0.2. Using the 0.8 criterion, we can expected that in Milford Sound an effect size of 3 or more will be detected with the current sample size of 12 per treatment, but an effect size of 2 would not be detected in one of three instances. The lower numbers of fish in Doubtful Sound make the current design less effective. Even an effect size of 3.5 would not be detected at The Gut. Although increased numbers of deployments would aid in detecting treatment differences, the overriding problem is low abundance of blue cod in all treatment groups. If more fish were observed per set, effect sizes would stabilize and smaller effects would be statistically detectable.

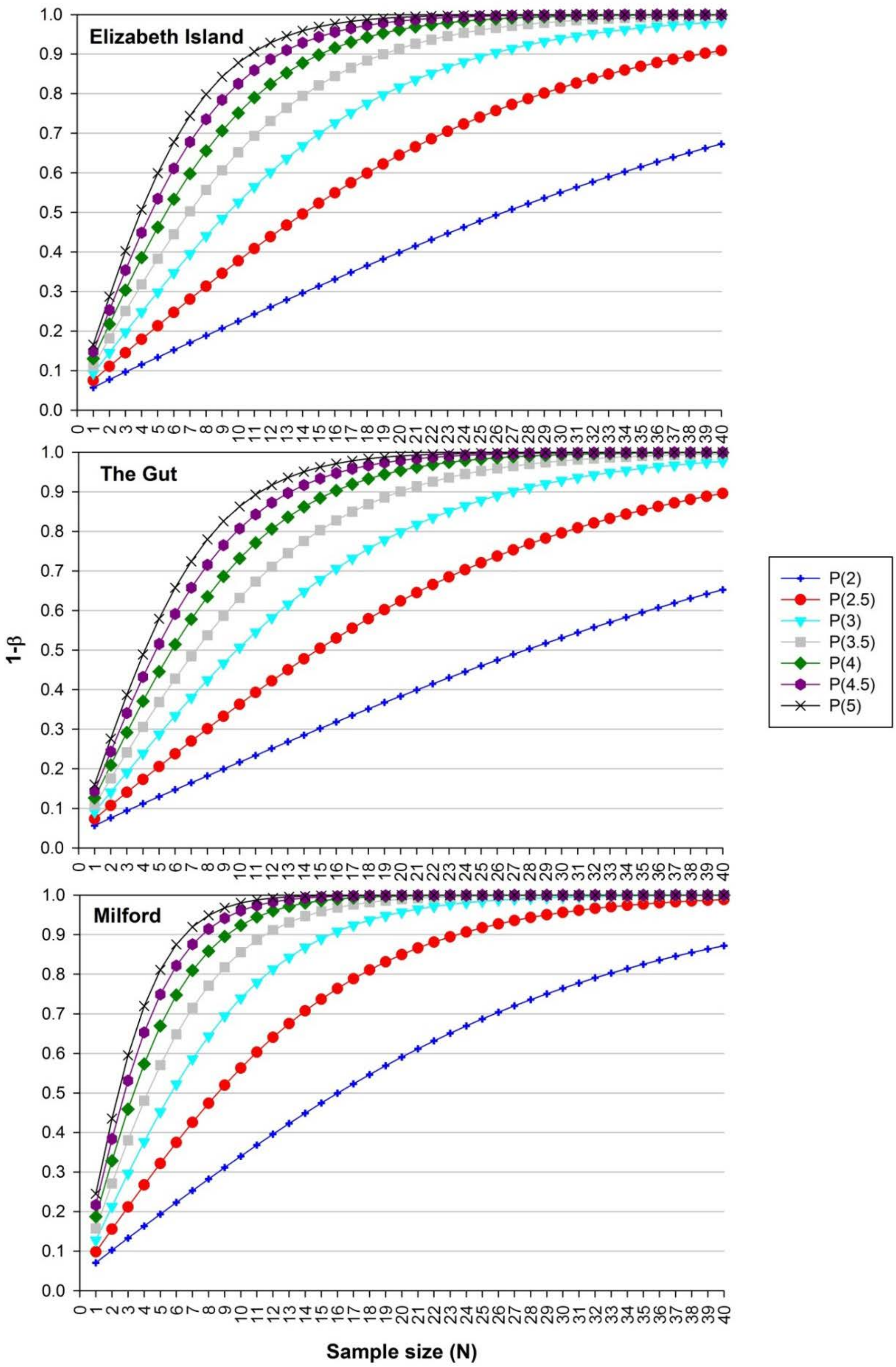

Figure 11: ***Post hoc*** **analysis of statistical power for blue cod surveys at three Fiordland marine reserves (comparing reserves with areas closed to fishing in 2005). Each curve represents the change in statistical power (1-β) of the comparison with increasing sample size for a given effect size, where P(2) = reserve density is 2× closed, P(2.5) = reserve density is 2.5× closed, etc.**

Tarakihi

The distribution of numbers and biomass of tarakihi were similar to those of blue cod, with the highest densities found on the open coast, and generally low numbers inside the fiords (Figures 12–15). As with blue cod, there were some differences in variability with respect to management zone. Reserve densities were generally higher than adjacent areas (which are closed to blue cod fishing, but not to tarakihi fishing, Figure 16). Over the four reserves surveyed, tarakihi numbers were 2.04 times higher in reserves (95% CL 1.01, 4.13, χ^2 = 4.05, p = 0.0443), but biomass was not significantly higher at only 1.74 times higher in reserves (95% CL 0.88, 3.44, χ^2 = 2.61, p = 0.1059).

The size range of tarakihi in Doubtful Sound did not differ among management zones, but the numbers observed were low so meaningful comparisons cannot be made (Figure 17). In Milford Sound, the inner fiord size ranges were similar to that in Doubtful Sound, but the “Outside” area (open coast and fiord entrance) contained no small fish and relatively more large (larger than 40 cm) tarakihi (Figure 17). This is in contrast to the size distribution of blue cod, where small fish were more abundant outside the fiords.

At the individual reserve level, densities varied among locations (Table 3). The only reserve to contain significantly higher numbers and biomass of tarakihi than its associated control areas was The Gut, but numbers were low overall. At Gaer Arm, numbers and biomass were significantly higher in the area outside the reserve (Table 3).

Table 3: Density and biomass means, ratios (Reserve:Closed) with 95% confidence limits, and results of maximum likelihood tests for the ratios at four Fiordland marine reserves for tarakihi *Nemadactylus macropterus* numbers and biomass.

Reserve	Reserve mean	Closed mean	Reserve:Closed ratio	Lower 95% CL for ratio	Upper 95% CL for ratio	χ^2	p
Tarakihi numbers							
Elizabeth Island	1.67	0.75	2.22	0.80	6.17	2.24	0.1347
Gaer Arm	0.25	1.00	0.25	0.03	2.05	2.09	0.1487
The Gut	0.75	0.12	6.00	1.05	34.05	4.93	0.0263
Milford Sound	1.81	1.09	1.67	0.59	4.71	0.96	0.3271
Tarakihi biomass							
Elizabeth Island	1.82	0.57	3.17	1.06	9.49	4.19	0.0406
Gaer Arm	0.11	1.48	13.89	0.76	252.97	6.51	0.0107
The Gut	0.53	0.06	9.51	1.52	59.60	8.20	0.0042
Milford Sound	0.81	0.71	1.14	0.45	2.89	0.08	0.7744

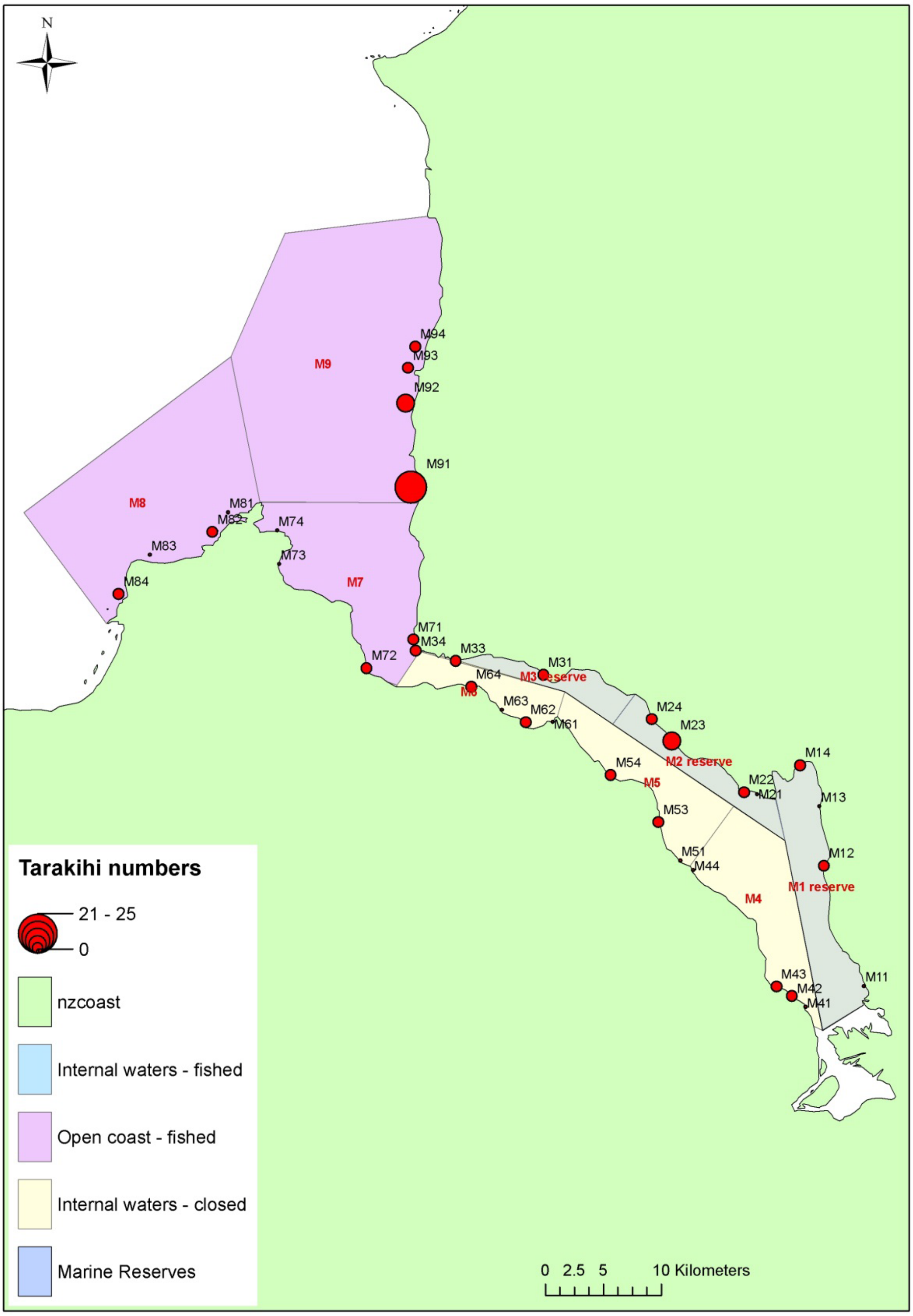

Figure 12: Numbers of tarakihi *Nemadactylus macropterus* observed in Milford Sound. The size of the red circles represents the number of fish observed, and a dot represents a zero count.

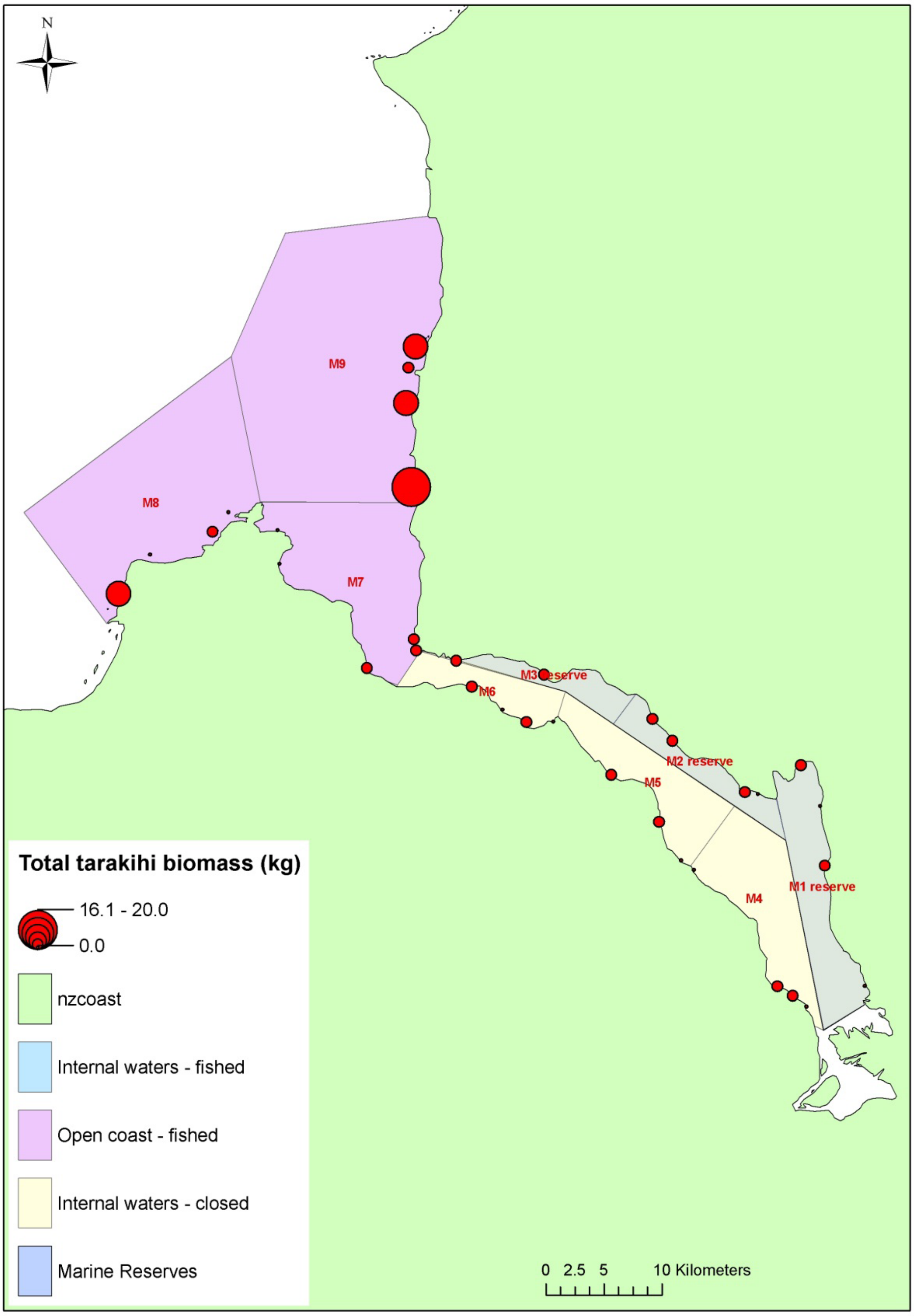

Figure 13: Distribution of biomass (kg) of tarakihi *Nemadactylus macropterus* in Milford Sound. The size of the red circles represents the biomass of fish observed, and a dot represents a zero.

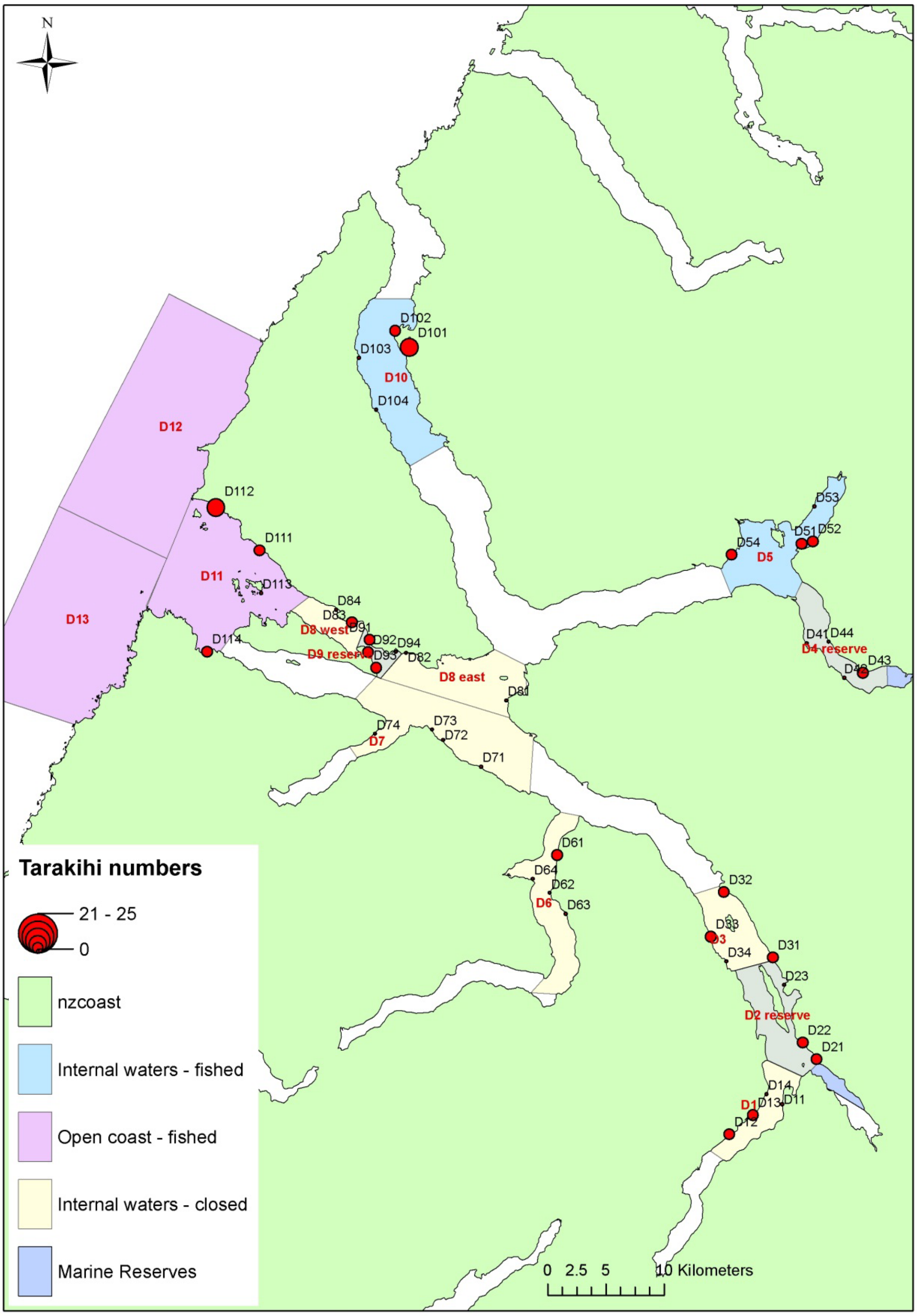

Figure 14: Numbers of tarakihi *Nemadactylus macropterus* observed in the Doubtful Sound complex. The size of the red circles represents the numbers of fish observed, and a dot represents a zero count.

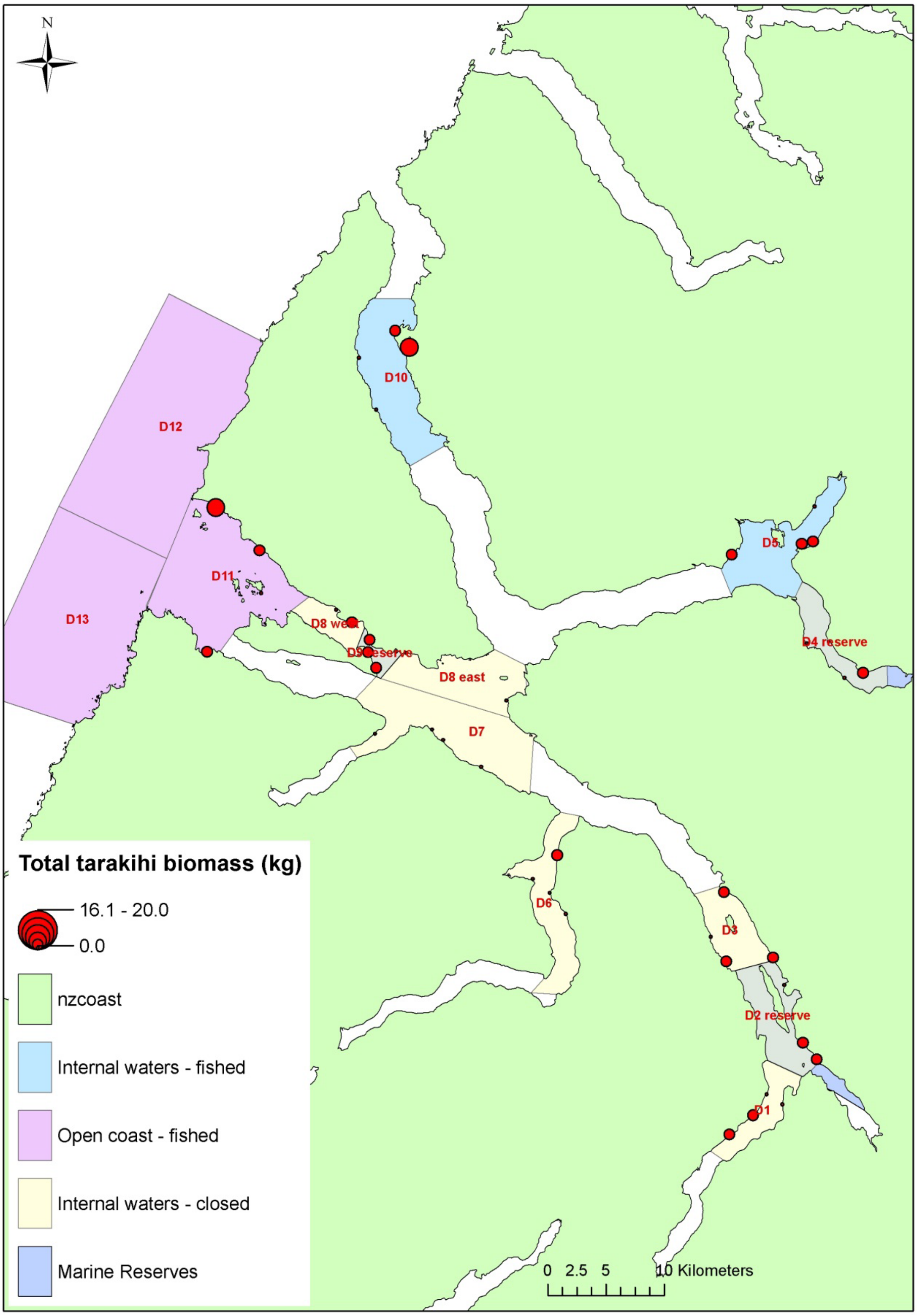

Figure 15: Distribution of biomass (kg) of tarakihi *Nemadactylus macropterus* in the Doubtful Sound area. The size of the red circles represents the biomass of fish observed, and a dot represents a zero.

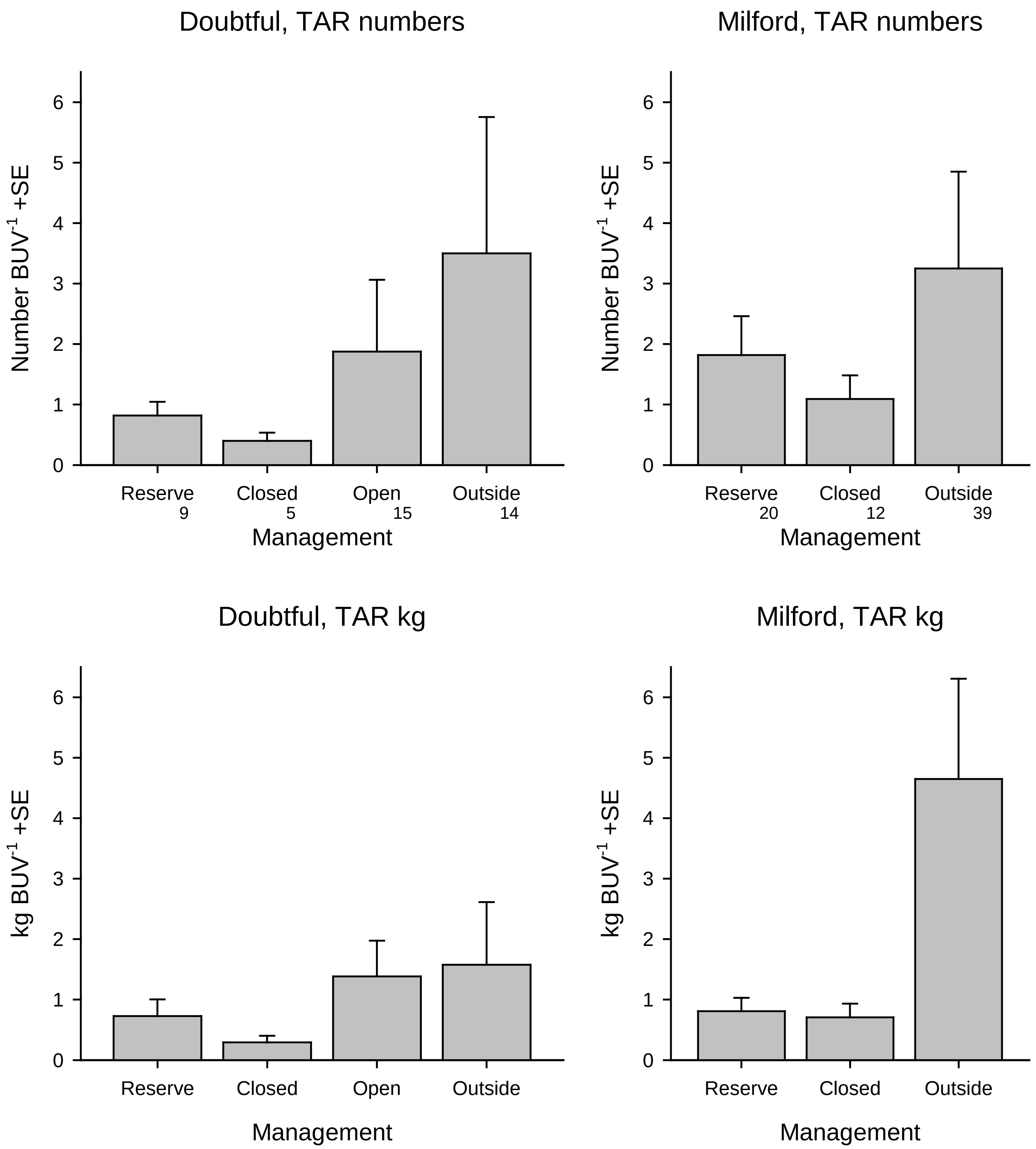

Figure 16: Relative density and biomass of tarakihi *Nemadactylus macropterus* in different management zones of the Doubtful Sound complex and Milford Sound. Numbers under management zone labels indicate sample size.

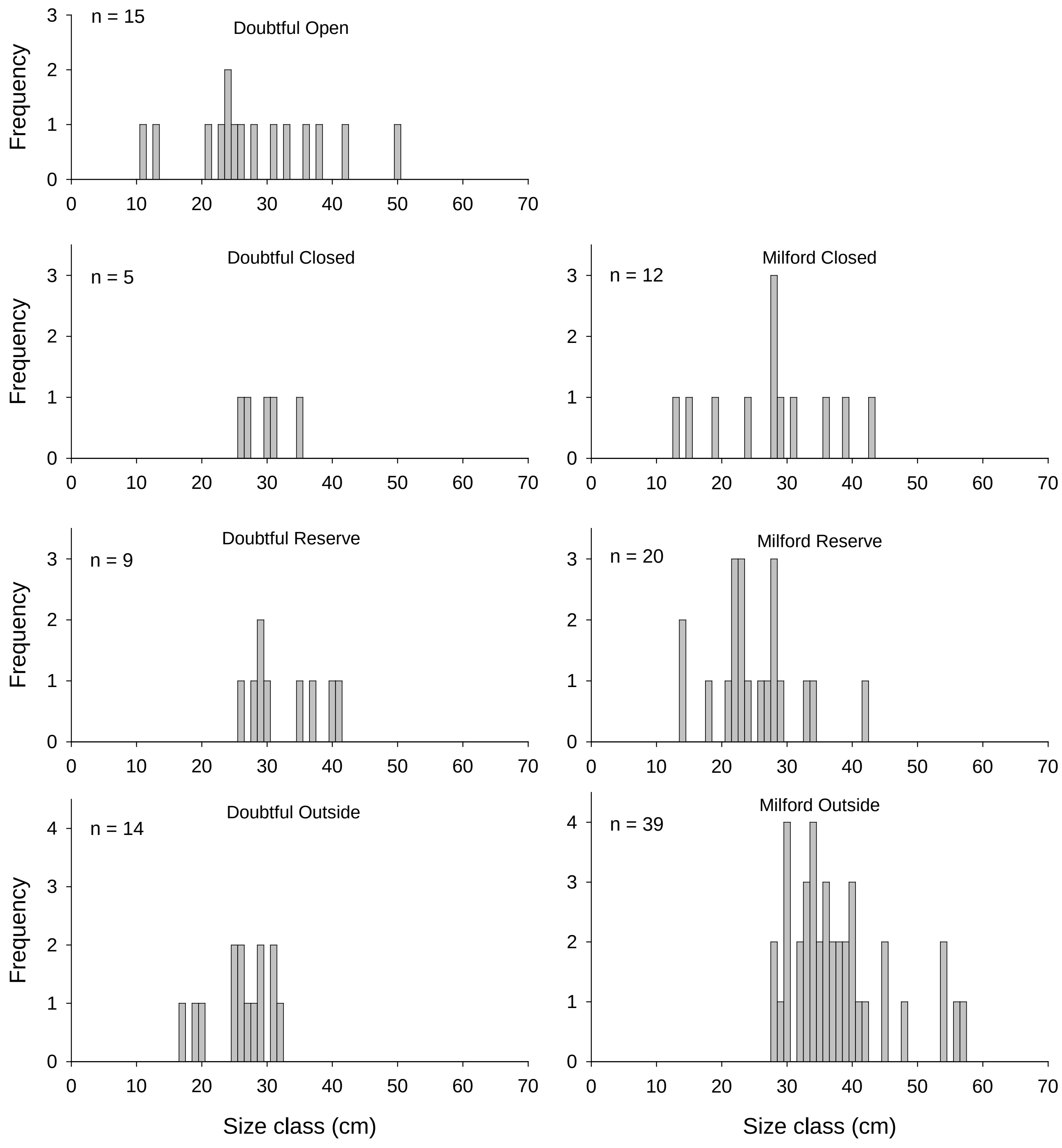

Figure 17: Size frequency of tarakihi in different management zones of the Doubtful Sound complex and Milford Sound.

4 DISCUSSION

The density of blue cod in inner fiord habitats is low relative to open coast and shallower coastal inlets elsewhere. There appears to be little recruitment of juvenile blue cod into the fiords, which is likely to be due to of a lack of suitable habitat in inner fiord areas. Juvenile blue cod (including postsettlement juveniles of only a few centimetres in length) are known to be found in relatively flat areas of reef and cobble bottoms (R Cole, R. Davison and K. Grange, unpubl. data) but such habitat is rare in the fiords. Small cod are locally abundant on soft sediment bottoms near fiord entrances and sills, but were not detected on rock wall habitats during this survey or in earlier visual census transect surveys (Willis et al. 2009). The implication of this is that inner fiord populations of blue cod may be entirely dependent on immigration of larger fish from source populations on the open coast (Carbines & McKenzie 2004).

Density comparisons within Milford Sound was limited to the marine reserve (north wall) versus closed fishery (south wall) versus outside the fiords (with fishing), since no fishable areas (for blue cod) exist within Milford Sound. The open coast is fished, yet contained 4–5 times the density of blue cod compared to protected inner fiord areas, and mostly small blue cod. We may conclude therefore that either fishing results in more small blue cod, that habitat differences are responsible for the observed density differences, or both. Similarly the Doubtful Sound complex included only two nominally fished areas that were outside Doubtful Sound (in Thompson Sound and Bradshaw Sound), and therefore neither were valid controls for the effects of protection in the Gut and Elizabeth Island marine reserves.

In Doubtful Sound, the marine reserves were implemented at the same time as the blue cod fishery closure – with the exception of the very small Gut area. While the the density of blue cod was statistically higher in The Gut compared to recent closed areas, both areas contained very few fish. The difference was more pronounced in biomass, with The Gut containing nearly 13 times the biomass of blue cod than adjacent areas, though this is due to the presence of two large fish in The Gut and two small fish in the closed areas. Both areas have been closed to blue cod fishing since 2005, but densities and biomass remain low. In Milford Sound, where the density of blue cod did not differ between reserve and closed areas in either numbers or biomass, the comparison consists of only about 20 fish observed in each area resulting from 11 sets in each stratum.

The low densities observed are consistent with earlier surveys in other Fiordland reserves conducted by divers using UVC methods (Willis et al. 2009) The only reserve surveyed by both studies was Gaer Arm, which in the UVC survey recorded four blue cod inside the reserve from three sites, each of which comprised six 25 by 5 m transects, and two fish from outside the reserve. In this and at other locations, the two studies agreed that blue cod densities decline with distance from the fiord entrance. Low densities of blue cod were also found over several years of line fishing surveys (Key 2010). This survey had similar numbers of fish observed at stations and with similar size frequencies despite differences in selectivity of the two survey methods.

The very low densities of blue cod found in both marine reserves and closed areas – irrespective of the length of time management measures had been in place – suggests that either compliance with the regulations is poor, the habitats are not optimal for blue cod or the colonisation rate of blue cod is very slow (if historical densities were indeed higher than present). A lack of juvenile blue cod inside the fiords points to habitat differences as being a primary cause of the lower than expected densities. Blue cod tend to be most common on flat ground but associated with structure (reefs, cobbles, or biogenic elements), and the precipitous nature of inner fiord habitats is not preferred blue cod habitat.

The results for tarakihi are even less robust. More tarakihi were found at Milford Sound than Doubtful Sound, but numbers were so low that comparisons are not useful. Baited underwater video may not be an appropriate survey tool for tarakihi which are known to school. They are also more difficult to measure as they are not close to the bottom, making the translation of length to biomass biased.

Although tarakihi are more mobile than blue cod, they were not observed in inner fiord reserves to any great extent. The fiords appear to be suboptimal habitat for tarakihi, although it is possible that some fish may become resident there. Tarakihi tend not to be amenable to diver surveys, and were counted only in very low numbers in the fiords by Willis et al. (2009) and Key (2010).

Power analysis suggests that sample sizes needed to increase in order to detect differences among treatment groups. Much of the variability in density observed was due to the lack of fish in 40% of the sample sites, in addition to this 28% of stations had only a single blue cod observed. This made it difficult to detect any changes in density among areas.

5 CONCLUSIONS

Despite closures since 2005, blue cod densities in both Milford and Doubtful Sounds are extremely low, and too low to reliably detect any meaningful differences in abundance due to spatial management actions.

Small blue cod were only observed in numbers outside the Sounds, suggesting the open coast is a source for immigration into the fiords and also provides better juvenile habitat.

Tarakihi were less abundant than blue cod in both Sounds, but like blue cod, were most abundant outside the fiords. Unlike blue cod, small tarakihi were observed inside the fiords but not outside.

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