Report to Department of Environment, Water and Natural Resources, South Australia

"Detecting changes in biodiversity indicators in South Australia's Marine Parks: Encounter Marine Park"

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Contents

1 Executive summary

- The overarching goal was to determine the magnitudes and patterns of spatial and temporal variation in a range of variables that may be useful indicators of changes in marine biodiversity associated with protection in Marine Park sanctuaries and restricted access zones, and to use these results to determine the power and precision of various sampling design strategies to detect changes.
- The complexities of analyses associated with evaluating a monitoring plan on this scale preclude traditional power analysis methods, so we used a flexible simulation-based approach (i.e., Monte Carlo) to calculate power across a range of sampling designs.
- We used data collected by underwater visual census on the total abundance and biomass of "fished" species, as well as abundance and biomass for a range of fish and invertebrate "indicator" species in the Fleurieu region Encounter Marine Park as the basis for the simulation analyses. This region represents one of only two Marine Parks sampled with sufficient temporal replication for estimating variation over time.
- We estimated the power to detect an average difference in a range of indicator variables inside and outside of the Marine Park sanctuary zones, and the power to detect a linear trend over specified time periods post-implementation of sanctuary zones relative to a no-change pattern outside the sanctuaries for sampling designs that varied in both their levels of spatial replication (i.e., sanctuary zones and sites) and the duration of sampling post-implementation of a Marine Park.
- Two estimates of change in abundance (or biomass) indicators following implementation of a Marine Park were calculated: (1) mean fold difference, and (2) linear fold change. The results are summarised visually as plots of power curves for each of these measures. We also calculated the minimum detectable differences, and minimum detectable trends with 80% power for each sampling design configuration that was evaluated.
- Simulations show that with a minimum of two sanctuary zones, eight years of sampling would allow detection of 20% average increases in total abundance of fished species with power of >80%.
- There are obvious improvements in the minimum detectable difference between inside and outside sanctuary sites when increasing the number of spatial replicates, and increasing the number of sanctuary zones tends to provide greater benefits (i.e., larger

reductions in the minimum detectable difference) than increasing the number of sites inside and outside of a sanctuary. With four zones with four replicate sites inside and outside each zone, detecting minimum total differences in abundance of 25% would be possible after eight years.

- Annual linear increases in total abundance of fished species of less than 20% are only achievable after eight years of sampling when the design includes two or more sanctuary zones with four replicate sites inside and outside the sanctuary.
- Greater temporal variation in biomass of fished species generally results in larger percent minimum detectable differences (and linear trends) for a particular sampling design scenario in comparison with detectable differences of total abundance.
- The effective differences in power between biomass and abundance may be a consequence of relatively small population sizes of fished species observed prior to protection in the Encounter Marine Park. Consequently, biomass indicators may become less variable once the local populations recover and reach more stable age distributions.
- Detection of 50% increases in the abundance of the indicator species bluethroat wrasse, blacklip abalone, and sweep were possible after four years of sampling. The precision of detectable trends for blue groper, harlequin fish, greenlip abalone, and rock lobster were low under most sampling scenarios examined. These species are, individually, not very useful indicators of change.
- Detectable biomass differences inside sanctuary zones for the indicator fish species were generally much higher than would be required from useful indicators.

2 Recommendations

- It is necessary to decide, based on estimates of power and detection from the simulation results in this report, on the magnitudes of change, the so-called "effect sizes", that are likely to indicate biologically meaningful consequences of the protections provided by the implementation of the marine park management plans. Changes to the current monitoring strategy, in terms of current distribution of resources to replication of sanctuaries and sites and the future sampling effort in the Encounter and other Marine Parks can then be made.
- At the time of preparation of this report, there was no temporal data available from the current monitoring of marine communities using baited remote underwater video surveys (BRUVS). We recommend that these data should also be evaluated to determine the suitability of this sampling approach for monitoring the effectiveness of Marine Parks. Two approaches could be used: (1) analyse the BRUVS data currently being collected and processed from repeat visits to existing monitoring sites, and/or (2) use the existing spatially-replicated BRUVS data to estimate spatial variation, and simulate under multiple scenarios for the magnitude of temporal variation that are informed by our understanding of temporal variation from the dive data. This would allow an evaluation of the sampling design required to use BRUVS data for monitoring change.

- The analyses undertaken to inform the monitoring design are based on best estimates of the variance components from the existing data. However, the data are limited in most Marine Parks and so it is critical that these estimates are improved as more data are collected. As such, an adaptive approach should be taken to the monitoring program, informed by annual updates based on analyses that incorporate new monitoring data. This approach may result in altering the number of sites or frequency of sampling as more information becomes available.
- Following on from the previous point, the existing monitoring data for the Lower Spencer Gulf and Yorke Peninsula Marine Park area includes temporal replication, so the analyses presented in this report should be extended to include analysis of this region, specifically in the evaluation of the spatial and temporal variance components. Where these variances differ from the Encounter Marine Park, further simulation should be undertaken to further understand the consequence of different relative magnitudes of spatial and temporal variance on the power and precision associated with measures of change in the marine biodiversity.
- Biomass measures are expected to provide sensitive indications of system health by showing differences relating to greater numbers of fish in larger size classes. Now that the Marine Parks have been established, continued monitoring will provide more robust estimates of variation in biomass at all spatial and temporal scales, which will show whether biomass is an effective monitoring indicator.

3 Introduction

A primary goal for the Monitoring, Evaluation and Reporting (MER) Program by the Department of Environment, Water and Natural Resources, South Australia, is to assess the impact of Marine Parks on ecological and socio-economic values (Bryars *et al.* 2017). One approach to understanding the ecological values is to monitor change in the abundance and biomass of key indicator species, and collections of species, inside and outside of different zone types of Marine Parks (MP). This report aims to inform the sampling design of the MER Program, and therefore this report focuses specifically on the reporting of ecological values. The MER Program will be focused on answering the question "have the Marine Parks protected and conserved marine biodiversity". The design of the MER program is critical to its success.

A successful monitoring strategy is contingent upon a carefully considered sampling design that is framed around clear questions based on realistic objectives. In this report, we assess the currently available marine monitoring data sets collected by divers using underwater visual census for South Australian Marine Parks and surrounding areas. The goal is to determine the magnitudes and patterns of spatial and temporal variation in a range of variables that may be useful indicators of change in marine biodiversity associated with changes in levels of protection in Marine Park sanctuaries and restricted access zones. Some of the key challenges for the MER program are to understand: (a) the ability to detect change, (b) the ability to attribute change to Marine Park management, and (c) deciding on a management response to observed change. Other important issues to address in planning a monitoring study are the spatial and temporal scale (and the ecological scale in terms of individual species versus

communities) for collection, analysis and reporting.

Evaluating a complex and broad-scale monitoring agenda, such as the MER Program, requires detailed knowledge of the relative amounts of variation in space and time, at relevant scales, of the indicator variables that can be used to evaluate changes in the system. In addition, it is necessary to decide on the magnitudes of change, the so-called "effect sizes", that are likely to indicate biologically meaningful consequences of the protections provided by the implementation of the marine parks management plans. The complexities of the analyses associated with evaluating a monitoring plan on this scale often preclude traditional power analysis methods based on analytical formulae (Urquhart 2012).

In addition to the complexity of the monitoring design, standard methods for estimating power to detect effects are suitable only for simple statistical models, such as *t*-tests and ANOVA, which are generally not suitable for ecological data that often consist of counts or presence-absence occupancy records. These types of data require more sophisticated statistical models to handle non-Normal patterns of variance, and when accompanied by multiple sources of variation, such as at multiple spatial and temporal scales, we use generalised linear mixed models (GLMM) to account for these complexities (Bolker *et al.* 2009; Zuur *et al.* 2013). Power analysis for monitoring designs based on these types of data and models therefore becomes a more complicated task. A flexible approach to calculating power in these situations is to use Monte Carlo simulation (Robert and Casella 2004, Johnson *et al.* 2015).

The approach taken for this report was firstly to use GLMM to analyse the existing Marine Park monitoring data to estimate components of spatial and temporal variation in a range of abundance and biomass indicator variables (described in detail below). We then used the estimates of the components of variance from these analyses to run simulation-based power analyses based on the Fleurieu region (Encounter Marine Park). We estimated the power to detect an average difference in a range of indicator variables inside and outside of the Marine Park sanctuary zones, and the power to detect a linear trend over specified time periods post-implementation of sanctuary zones relative to a no-change pattern outside the sanctuaries for sampling designs that varied in both their levels of spatial replication (i.e., sanctuary zones and sites) and the duration of sampling post-implementation of a Marine Park. The results are summarised as a series of power curves and estimates of minimum detectable differences and minimum detectable trends for each design combination.

4 Methods

4.1 Quantitative monitoring design

Careful monitoring design ensures a meaningful outcome of monitoring efforts, avoids wasting (limited) resources, and ensures that relevant differences can be detected in the most efficient way. Power analysis requires explicit consideration of what constitutes a biologically significant result. It is a means of quantifying whether a given amount and configuration of sampling effort is likely to identify a biologically significant effect size.

Power is defined as the probability of rejecting the null hypothesis when it is false. It is the

probability of detecting an effect, given that one exists, and depends on sample size, effect size, amount of variability in response variable, and the pre-defined significance level used. The aim of a power analysis is to predict the power of a particular experimental design, or the sample size required to achieve an acceptable level of power. Conventionally, 80% power is deemed adequate, although often without justification. So essentially we wish to **calculate the power** of a particular sampling design **by specifying** the **sample size** (i.e., number of replicates - at all levels of the sampling design if there are hierarchies, such as spatial and/or temporal scales), **size of the difference**, or trend, that is biologically meaningful, an estimate(s) of **variance** (again, at each level if there are hierarchies of scales), and the *a priori* **level of acceptable error** in rejecting the null hypothesis. Alternatively, it can be helpful to interchange the focal component of that equation (i.e., power) with another component (e.g., the detectable difference). In doing so, we could fix (i.e., hold at a constant value) the power (usually at 0.8 = 80% as mentioned above) and then estimate the minimum detectable difference for that level of power. We will estimate power using a simulation approach, and based on the results then estimate the minimum detectable difference for each potential biodiversity indicator variable under a range of sampling designs that replicate zones, sites, and numbers of sampling occasions after Marine Park establishment. The results will be summarised to infer the adequacy of the current monitoring strategy, and to identify which variables are sensitive indicators of change.

4.2 Existing sampling design in SA marine parks MER Program

The current marine benthic sampling program using transect sampling by divers (underwater visual census) is undertaken by DEWNR in several of South Australia's Marine Parks. However, the Encounter Marine Park (Figure 1) is one of only two Parks where sites have been revisited on multiple occasions providing repeated samples through time. The existing design for Encounter MP can be represented in the following schematic way:

$$\frac{\frac{(SanctuaryZone_4^r * InsideOutside_2^f)}{Site_4^r} * Year^r_{n_{Before}/n_{After}}}{Transect_4^r} \quad (1)$$

Sanctuary Zone classifies groups of *Sites* according to their specific zone; *InsideOutside* classifies groups of *Sites* inside the sanctuary versus control *Sites* outside (but adjacent to) the sanctuary. So *Sanctuary Zone* and *InsideOutside* are crossed factors, with *InsideOutside* representing the fixed comparison of interest. *Sanctuary Zones* could be treated as fixed or random depending on how they were drawn from all zones within a Marine Park and how whether the intended inferences are to be restricted to the specific zones used, or applied more generally to infer regional patterns. They are treated as random factors for all analyses presented in this report. *Sites* are selected randomly and independently within each level of that cross-classification. The standard design is to have four randomly-chosen *Sites* inside and four randomly-chosen *Sites* outside of each sanctuary.

When sanctuary zones are revisited in subsequent years, divers return to the same (marked) *Sites*. So, in the schematic above, the *Sites nested within Zone*InsideOutside* are crossed with

survey *Years*. The *Sites* are initially surveyed for multiple *Years* prior to the establishment of the Marine Park (n_{Before}), and then surveyed in subsequent *Years* (n_{After}).

Four *Transects* are randomly selected *Site*$^{-1}$. *Transects* are placed randomly at each return visit, so the repeated measurements are taken at the *Site* scale of the sampling design. Consequently, data are summed over *Transects* prior to further analysis, as is routinely done for previous evaluations of the marine benthic sampling program.

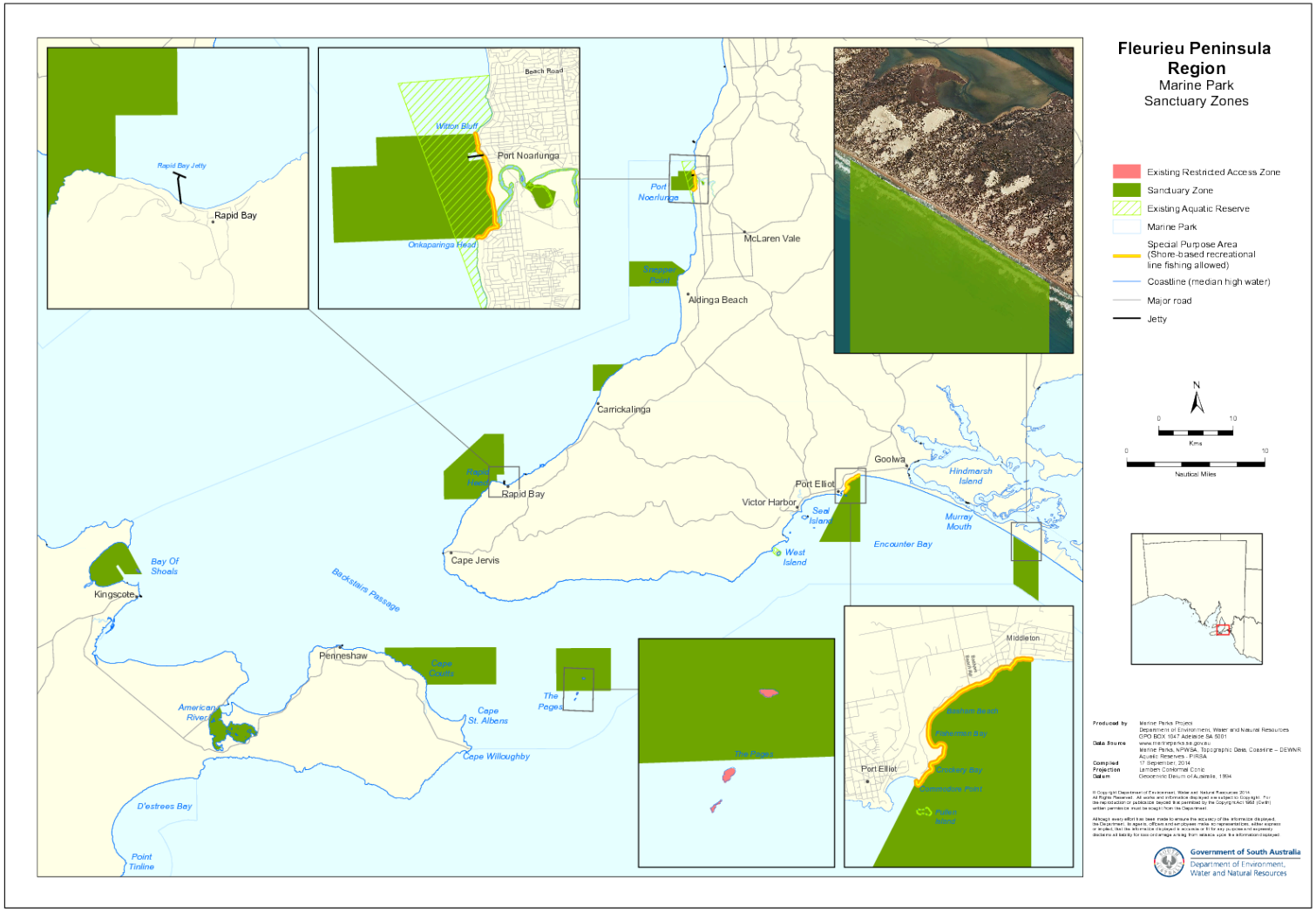

Figure 1. Encounter Marine Park sanctuary zones in the Fleurieu Peninsula region of South Australia.

4.3 Indicator species and aggregated species abundance and biomass variables

The abundances of all fished species (defined as species that are susceptible to capture by conventional fishing methods, e.g., line, spear, pot, and net; Supplementary Table 5) were pooled to provide an indication of the total size of the resource that is fished in the Marine Park. The expectation is that this total population will increase following the implementation of the Marine Park protections. The size class of all individual fish counted on a transect is also recorded by the divers. Length-weight relationships are used to calculate biomass for the species from the abundance and size class information. Biomass provides additional information regarding the effectiveness of Marine Parks by showing changes to the size-distribution (and hence age structure) of a species, which is hypothesised to result in more, larger fish in protected sanctuary zones (that are potentially more resilient to other disturbances).

In addition to the pooled abundances across fished species, several indicator species that are potentially suitable for detecting changes in Marine Parks were assessed. We examined the abundances and biomass of four fish species: blue groper (*Achoerodus gouldii*), bluethroat wrasse (*Notolabrus tetricus*), harlequin fish (*Othos dentex*), and sweep (*Scorpis aequipinnis*). We also assessed the abundances of three invertebrate species: greenlip abalone (*Haliotis laevigata*), blacklip abalone (*Haliotis rubra*), and rock lobster (*Jasus edwardsii*).

4.4 Conceptual model for effects of marine park rezoning

Figure 2 shows a conceptual model for changes in abundance (or equivalently biomass, or some other appropriate response variable) over time, and how these changes might differ inside and outside of Marine Park sanctuary zones.

In order to evaluate the power of any given sampling design to detect changes in a response variable due to the effects of sanctuary zones, it is necessary to calculate all of the sources of variability that are represented in the conceptual model – i.e., zone-zone, site-site and year-year variation, and variation in the interaction between space (zones) and time (years). Indeed, if we wish to consider the different spatial scales at which changes may occur, and therefore the appropriate spatial scale to distribute sampling effort, it is also necessary to estimate variation at hierarchical scales of sampling. For instance, in this report we will consider variation at the regional scale of "sanctuary zones" and the local scale of "sites within zones".

4.5 Generalised linear mixed models (random effects)

More complex analyses than simple linear models are generally required to analyse ecological monitoring data. Generalised linear mixed models (GLMM) incorporate random effects to accommodate multiple sources of random variation (e.g., within and between study sites and years). In addition, response measures such as counts that are common in ecological monitoring can not readily be analysed using t-tests and ANOVA, and consequently, the associated power analysis methods designed within that framework are inappropriate. GLMMs allow modelling of diverse response distributions (i.e., counts, proportions) and multiple sources

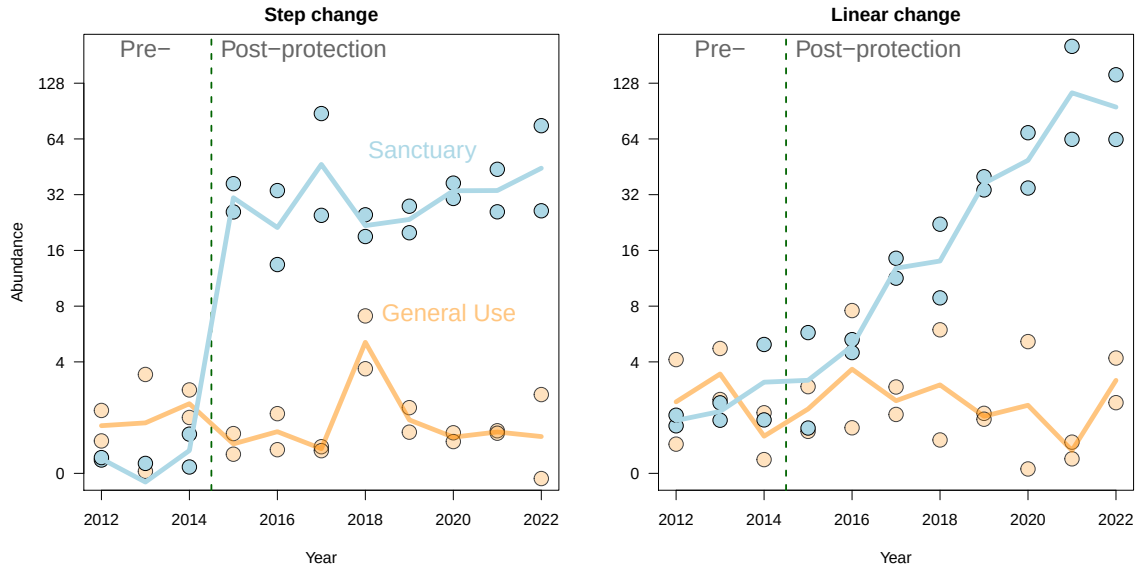

Figure 2. Conceptual model for effects of marine park protection on abundance of an example species. Points are *sites* sampled in each *year* in sanctuary (light blue) and general use (orange) zones. Black lines show annual variability averaged over multiple sites. The left panel depicts an immediate, positive step change in the response variable after the establishment of sanctuary zones, such that mean abundance is relatively stable (and has similar variance) in the pre- and post-protection stages, but differs inside and outside of sanctuary zones. The right panel depicts a more gradual linear change in the response variable in sanctuary zones following their establishment and no change in general use zones, such that the mean response diverges over time. In reality, the rate of linear change would likely decrease over time such that the response variable approached an asymptote that reflected an upper threshold density or biomass. For this report, we only consider the case of linear change and restrict our evaluations to the medium term (maximum of 12 years post-protection sampling).

of random variation, termed "random effects". Overdispersion in a GLMM fit (more variation than expected) has several potential causes, including missing or poorly modelled covariates, outliers, or zero-inflation. Accounting for realistic levels of random effects and overdispersion effects power and precision, and consequently has severe implications for study design (e.g., up to five-fold increases in sampling effort).

4.6 Simulation-based power analysis using GLMM

Power analysis can be defined more broadly as any attempt to quantify prospectively the 'informativeness' of a study (Johnson *et al.* 2015). This might include predicting the precision of an estimate, rather than just focusing on the more traditional power calculations. A more general and flexible approach is to use Monte Carlo simulation, which can also improve accuracy and provide a simple conceptual framework for interpretation.

4.6.1 Steps in simulation-based power analysis

1. Simulate many data sets under the assumption that the alternative hypothesis is true – i.e., that there are differences inside and outside of sanctuary zones, or that there is a trend of increasing abundance or biomass inside sanctuary zones relative to outside zones;
2. Carry out a statistical test of the null hypothesis that the mean difference, or trend differences are zero on each simulated data set;
3. Calculate the proportion of simulated data sets where the specified null hypothesis is rejected – this proportion is equal to the power to detect an effect.

The effect of different configurations for the sampling design, and the assumptions that underpin the design, on power can then be explored by repeating steps 1-3 across a range of different scenarios. For example, the number of replicates at different levels of the design can be varied, as can the time period over which change is projected, the range of possible effect sizes that are tested, and the magnitudes of the random effect variances at different levels of the design.

4.7 Statistical analysis of existing monitoring data

The following section provides a brief description of the data analysis presented in the report.

The Encounter Marine Park data consisted of seven sanctuary zones, including Carrickalinga Cliffs, Rapid Head, Encounter Bay, Sponge Gardens, The Pages, Aldinga Reef, and Port Noarlunga Reef. At each of these sanctuary locations, between one and eleven sites were sampled inside the sanctuary zone and outside the sanctuary zone. Data were available over ten years of revisits between 2005 and 2014 to sites in this region, though individual sites were not visited in all years.

Monitoring data was aggregated (summed) to site level prior to analysis (this aggregation does not affect the analysis because transects were randomly selected on each sampling trip, so the observational unit for repeated measures was the site).

Temporal sampling in the existing Marine Parks monitoring data does not include sequential annual sampling. Therefore, there is no information about temporal correlation in abundance or biomass measures. Such information is necessary for designing the intensity of temporal sampling of sites in monitoring studies, that is to say, sound decisions about sampling only a proportion of all monitoring sites each survey year in order to reduce sampling effort require knowledge of correlation through time. This information could be obtained through annual monitoring of sites over several years, which could then inform the adaptation of the sampling design. For example, if the correlation was relatively high then there would be justification for sampling only a subset of the sites in each survey year.

Abundance data was generally overdispersed so we analysed existing spatial and temporal patterns using GLMMs with a log link and negative binomial variance function (however, a

Poisson variance function was used where there was no evidence for overdispersion, but this was rare). Variance components were estimated for zones, sites within zones, years and the year by zone interaction. Differences in the summed site-level abundances due to different numbers of transects sampled at a site were accounted for by an offset term for the (log) number of transects per site. Model-estimated mean abundance (or biomass) was plotted to show starting values to be used in subsequent simulations.

Biomass can be a more difficult response variable to model because it is a continuous measure (in contrast to discrete measures such as counts), but the distribution is often (right) skewed and may contain a point mass at zero. To address these issues, we modelled biomass using GLMMs with a log link and Tweedie variance function (however, a Gamma distribution was used where there was no point mass at zero).

The results of the analysis of the existing data were summarised in tables showing estimates of mean abundance or biomass and differences inside and outside sanctuary zones (though there was little evidence for differences as the data were generally collected before the implementation of the Marine Park zoning). The tables also summarised model goodness-of-fit, the replication at each level of the hierarchical sampling design (i.e., zones and sites within zones) and the number of years. The tables also show the magnitudes of the estimated variance components that were used in subsequent data simulations. The intra-class correlation statistic was also calculated – this measure indicates the strength of correlation among observations within each random effect grouping level, providing a relative measure of the amount of variability due to that random effect that can be compared across response variables (and potentially among Marine Parks). Mean abundance (or biomass) inside and outside sanctuary zones was also plotted with 95% confidence intervals to indicate parameter precision.

4.8 Simulating data and calculating power and precision

We simulated 300 data sets for each combination of zone (1, 2, and 4) and site (2 and 4) replication with 2, 4, 8 and 12 years of sampling after the implementation of sanctuary zones. The starting mean of the response variable, and the magnitudes of zone, site and year (and their interaction) variances determined from the analyses of the existing monitoring data. In addition, the overdispersion parameters estimated from the existing observed data were used to generate the simulated series. The 300 simulated data sets were generated for each of the following annual fold changes in the response: 1.05, 1.1, 1.2, 1.5, 2, 3, 4, 6, and 10 (i.e., 5%, 10%, 20% etc) producing a total of 2700 simulated data sets.

Each simulated series was analysed using a generalised linear mixed model with a variance function matching that used to simulate the data (i.e., negative binomial for abundance counts, and a Gamma or Tweedie for biomass values). The models contained fixed terms for mean differences between the inside and outside of sanctuary zones, a linear temporal trend that differed inside and outside the zones, and the interaction between year and zone. The random effects included variation among zones, among sites within zones, among years, and the year by zone interaction. In each case, we calculate the proportion of simulated data sets where the specified null hypothesis was rejected (α = 0.05) as our estimate of power. We also retained estimates of the model parameters to ensure that the models recaptured the simulated trends

and differences. The estimates of the precision of these parameters were used to calculate the average precision of any detected differences.

Power analysis simulations, and the subsequent model fitting, are computationally demanding tasks. Given the large scale of the analysis (multiple response variables, multiple Marine Parks), the custom code base written in the R statistical and programming language (R Core Team 2017) by the author to simulate the data and fit the models to the simulated series included options to run in parallel across multiple compute nodes. The simulations were run in Linux virtual machines on the Nectar cloud (http://cloud.nectar.org.au/). All analyses were conducted using the R (R Core Team 2017).

4.8.1 Simulation summaries

The results of the simulations were collated and summarised graphically. We also provide an example of these graphs with explanations to assist the interpretation of the results (Figure 3).

Two estimates of change in abundance (or biomass; both on the log scale) following implementation of a Marine Park were calculated: (1) mean fold difference, and (2) linear fold change (Figure 4). Mean fold difference measures the total difference in abundance inside sanctuary zones versus outside zones averaged over the period of post-protection monitoring. Assuming there is some underlying trend of increasing abundance, the mean fold difference will increase over time. Linear fold change, on the other hand, is simply the slope of the linear trend over time inside of sanctuary zones (assuming no increase outside the sanctuary), which measures the increase in abundance per year. As we model the data using GLMMs on the logarithm scale, both of these measures represent additive differences, but these become multiplicative when back-transformed to the raw abundance count (or biomass value). Therefore, these measures refer to "fold" (i.e., multiplicative) changes.

The summary plots show the power to detect a positive trend (or a positive mean difference) inside sanctuary zones compared to sites outside the zones across the range of fold changes (or fold differences) that were simulated. Colours, line types and symbols were used to identify the number of replicate zones and the number of years of sampling post-sanctuary implementation that were summarised for each group of simulations. Similar plots were used to display the precision of the trend (or difference) estimates for each response variable.

To facilitate the translation of these results, we also calculated the minimum detectable fold change (MDC) and the minimum detectable fold difference (MDD) for each response variable across the simulated sampling design scenarios and magnitudes of annual change. We used linear interpolation to calculate the fold change value associated with 80% power from the estimates of change that lead to an inferred difference with 80% power. MDD estimates the average difference inside and outside of sanctuary zones at the midpoint of the simulated number of years sampling post-implementation of the sanctuary zones. These estimates were plotted together for groups of the response variables to allow easy comparisons.

All of the simulation summaries, figures, and tables provided are based on results using four sites inside and four sites outside of each sanctuary zone. Reducing this replication to two sites for each combination results in a consequent loss of power. The magnitude of the difference in

detectability due to changing the number of replicate sites from four to two will depend on the amount of site-level variation (shown in the Tables summarising the analysis of existing data) can be visualised in the plots summarising minimum detectable differences and minimum detectable linear changes.

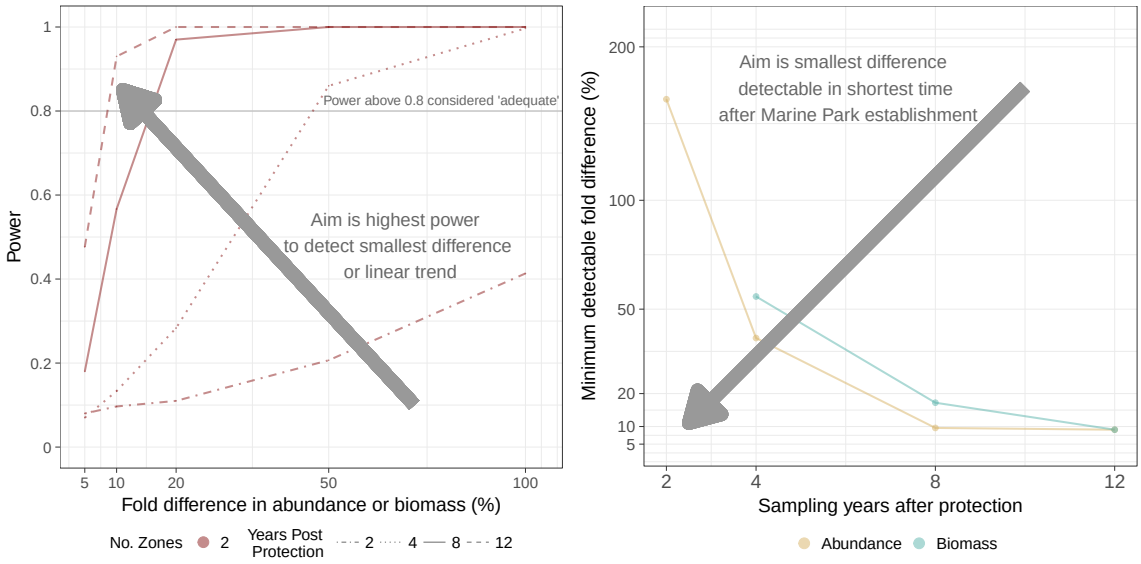

Figure 3. Explanation and interpretation of the summary plots that are presented in this report. Power analysis curves (left panel) are calculated for sampling designs with different numbers of replicate sanctuary zones and replicate sites inside and outside of sanctuary zones, and different numbers of years of follow-up monitoring after the establishment of the Marine Park (labelled "post-protection"). Optimal sampling designs will yield higher power for smaller magnitude differences in the average, or smaller annual linear trend, in abundance or biomass. Therefore, we try to identify sampling designs with the lowest spatial (number of zones) and temporal (number of years of sampling) effort that provide greater than 80% power (i.e., power = 0.8) to identify the smallest possible trends or average differences in the indicator variable of interest. We can then summarise the many possible sampling designs across many potential indicator variables by calculating these minimum detectable average differences (MDD), or minimum detectable linear changes (MDC), for each scenario (right panel). Using this calculated metric, we aim to evaluate the sampling strategy that affords the smallest difference detectable in the shortest time after the establishment of the Marine Park.

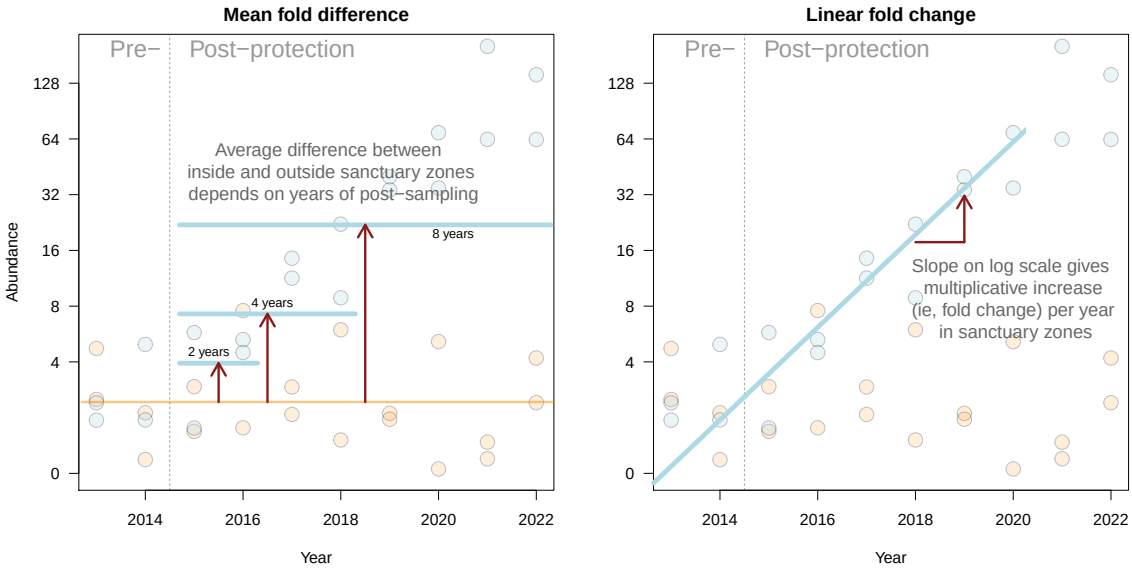

Figure 4. Conceptual interpretation of two estimates of change in abundance (or biomass; both on the log scale) following implementation of a Marine Park: mean fold difference (left panel) versus linear fold change (right panel). Mean fold difference measures the total difference in abundance inside sanctuary zones versus outside zones averaged over the period of post-protection monitoring. Assuming there is some underlying trend of increasing abundance, the mean fold difference will increase over time, as shown here for two, four, and eight years of monitoring. Linear fold change, on the other hand, is simply the slope of the linear trend over time inside of sanctuary zones (assuming no increase outside the sanctuary), which measures the increase in abundance per year. As we model the data on the logarithm scale, both of these measures represent additive differences, but these become multiplicative when back-transformed to the raw abundance count (or biomass value). Therefore, these measures refer to "fold" (i.e., multiplicative) changes. Power to detect both measures was calculated through simulations. Background points are *sites* sampled in each *year* in sanctuary (light blue) and general use (orange) zones.

5 Results

5.1 Integrated Summary: Minimum detectable changes in Fished species in Encounter MP

5.1.1 Total abundance of fished species

Using the existing monitoring data, variation in the total abundance of fished species in the Encounter MP was largest between sanctuary zones and between sites at a sanctuary zone. In contrast, variation among survey years, and variation among survey years between sanctuary zones, were relatively small (see variance components and intra-class correlations in Table 1). The average total abundance of fished species inside sanctuary zones was similar to outside the zones (Figure 5; Table 1).

Simulations show that with a minimum of two sanctuary zones, average increases in the abun-

dance of total fished species of at least 50% per year would be detectable with 80% power after two years of sampling following Marine Park establishment (Figure 6 - upper left panel). Increasing the number of sanctuary zones results in substantial increases in the power to detect differences. For example, average increases of at least 50% per year would be detectable with 97% power after two years if four sanctuary zones were sampled (Figure 6 - upper left).

Increasing the number of years of post-protection sampling also increases power substantially. Four years of sampling at two sanctuary zones would allow detection of 20% average annual increases in total abundance of fished species with power of 83%, and this improves to 99% power to detect minimum 10% changes after eight years of sampling (Figure 6 - upper left).

Changing the focus to detecting positive linear trends in abundance over time inside sanctuary zones following the establishment of a Marine Park relative to unprotected sites outside of the sanctuaries with adequate power requires greater sampling effort. Detecting 20% annual increases in total abundance of fished species with adequate power (i.e., >80%) requires at least two sanctuary zones and eight years of post-protection sampling (power = 97%; Figure 6 - upper right). Doubling the number of zones to four improves this to detecting 10% annual increases with power of 85%. Sampling for 12 years post-protection, even with four sanctuary zones, is not sufficient to detect 5% annual increases with 80% power (power = 77%; Figure 6 - upper right).

Figure 7 summarises the power analysis simulations to show the minimum detectable average differences (MDD) in total fished species abundances inside compared to outside of sanctuary zones for all combinations of the numbers of replicate sanctuary zones (rows) and sites (columns) across the number of years of sampling post-protection (x-axis) to allow quick comparisons. These summaries of MDD show the minimum average cumulative difference (increase) that can be detected over the years of post-protection sampling (rather than the annual increments that contribute to this overall difference).

There are obvious improvements in the minimum detectable difference between inside and outside sanctuary zones when increasing the number of spatial replicates, and increasing the number of sanctuary zones tends to provide greater benefits (i.e., larger reductions in the minimum detectable difference) than increasing the number of sites inside and outside of a sanctuary. Decisions about the target magnitudes of detectable differences can thus be made by trading off the cost of increasing the amount and scale of spatial sampling. For example, if the program target was to detect 50% increases in total fished species abundance, then a minimum of eight years of post-protection sampling would be required with a minimum of two zones with four replicate sites inside and outside each zone (Figure 7 - centre-right), or alternatively four zones with two replicate sites inside and outside each zone (Figure 7 - lower-left) would be required. With four zones with four replicate sites inside and outside each zone, detecting minimum total differences of 25% would be possible after eight years, and this reduces to 12% after 12 years (Figure 7 - lower-right).

Minimum detectable fold changes (MDC), that is, the minimum detectable linear trend, are summarised in a similar way in Figure 8. Annual linear increases in total abundance of fished species of less than 20% are only achievable after eight years of sampling when the design includes two or more sanctuary zones with four replicate sites inside and outside the sanctuary (Figure 8 - centre- and lower-right). A similar result occurs for the design with four zones and

two sites in each combination (Figure 8 - lower-left).

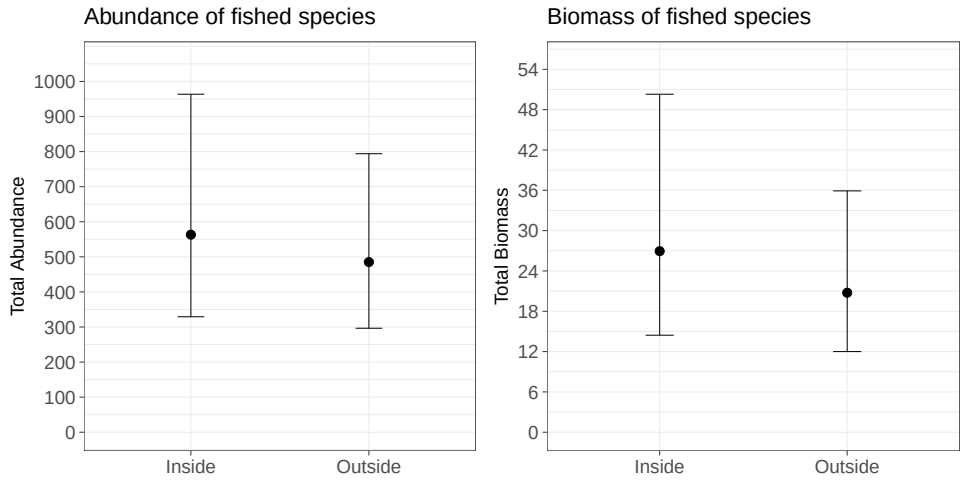

Figure 5. Estimated mean total abundance (left panel) and biomass (right panel) of fished species Inside and Outside of sanctuary zones in the Encounter Marine Park. Error bars are 95% confidence intervals.

5.1.2 Total biomass of fished species

As for total abundance, the average total biomass of fished species inside sanctuary zones was similar to outside the zones (Figure 5; Table 2), and variation was largest between sanctuary zones and between sites at a sanctuary zone. In contrast with patterns of variation in total abundance, there was also substantial variation in total biomass among years, and among years between sanctuary zones (Table 2).

Given that biomass was calculated from size class categorisation of the abundance counts, the larger relative variation in biomass among years indicates variability in the size class distribution (and by corollary the age distribution) among years. The greater temporal variation generally results in larger percent minimum detectable differences (and linear trends) for a particular sampling design scenario than were estimated for total abundance (Figure 6 and 7). For example, with a minimum of two sanctuary zones, average increases in the biomass of total fished species of at least 50% per year would be detectable with 80% power after four years of sampling - twice the duration that would be required to detect the same effect size for abundance (Figure 6 - lower left). Similar differences from the abundance estimates were shown for detection of linear trends in biomass (Figure 6 - lower right).

The contrast in results between biomass and abundance are most clear in the plots of MMM (7) and MDC (8), where the size of the minimum detected effects were consistently larger across all prospective sampling design configurations. These estimated minimum effects generally started to converge toward those for abundance as the number of years of sampling post-protection increased.

The effective differences in power between biomass and abundance could potentially be a consequence of the relatively small population sizes of fished species that are observed prior to protection in the Encounter Marine Parks. If so, biomass indicators may become less variable

once the local populations recover and reach more stable age distributions. Eventually, this may result in biomass measures that provide more sensitive indications of system health by showing differences relating to greater numbers of fish in larger size classes. Now that the Marine Parks have been established, continued monitoring will provide more robust estimates of variation at all spatial and temporal scales, and will allow us to determine whether biomass is an effective monitoring tool.

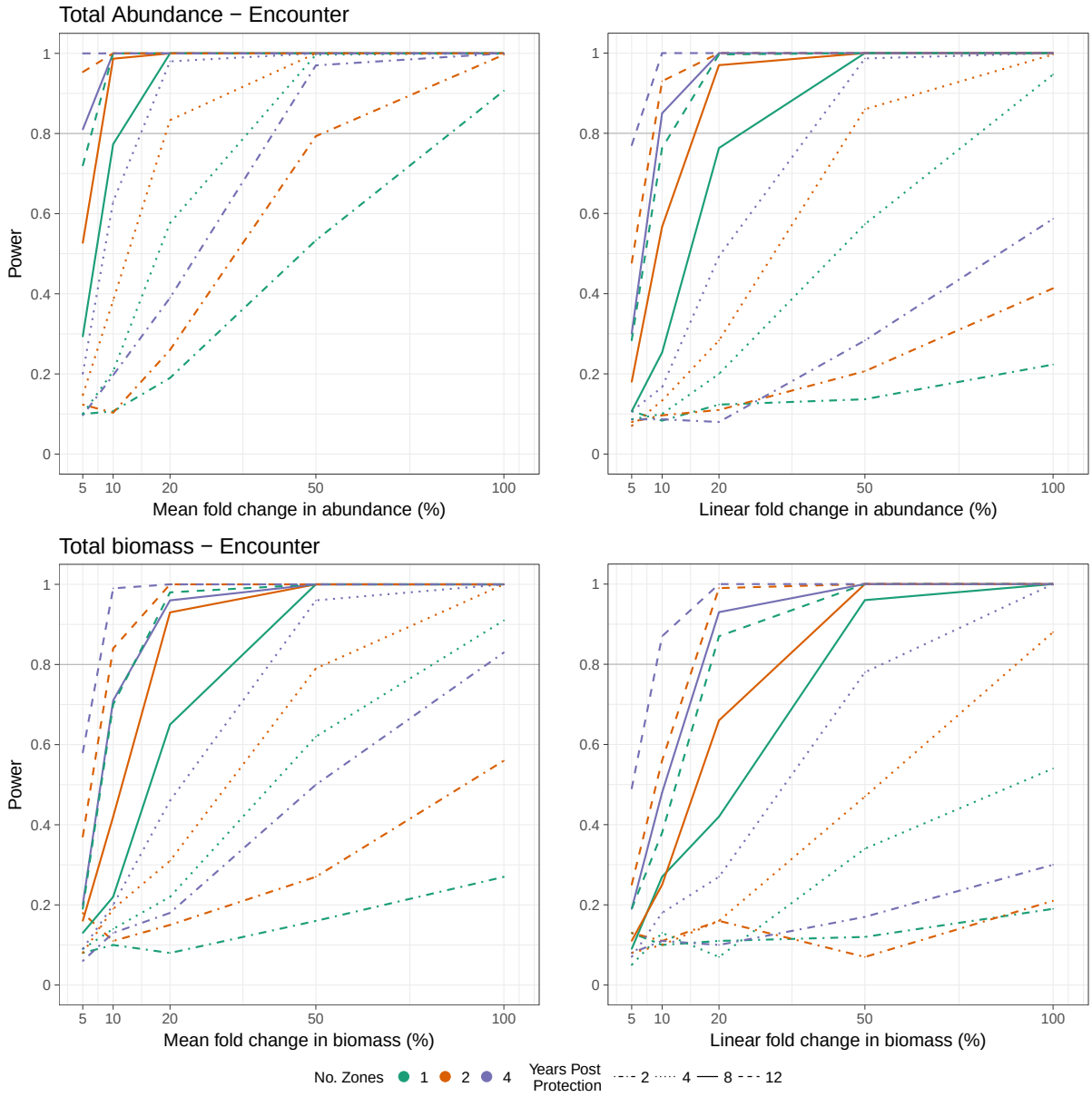

Figure 6. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in total abundance (upper row) and biomass (lower row) for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

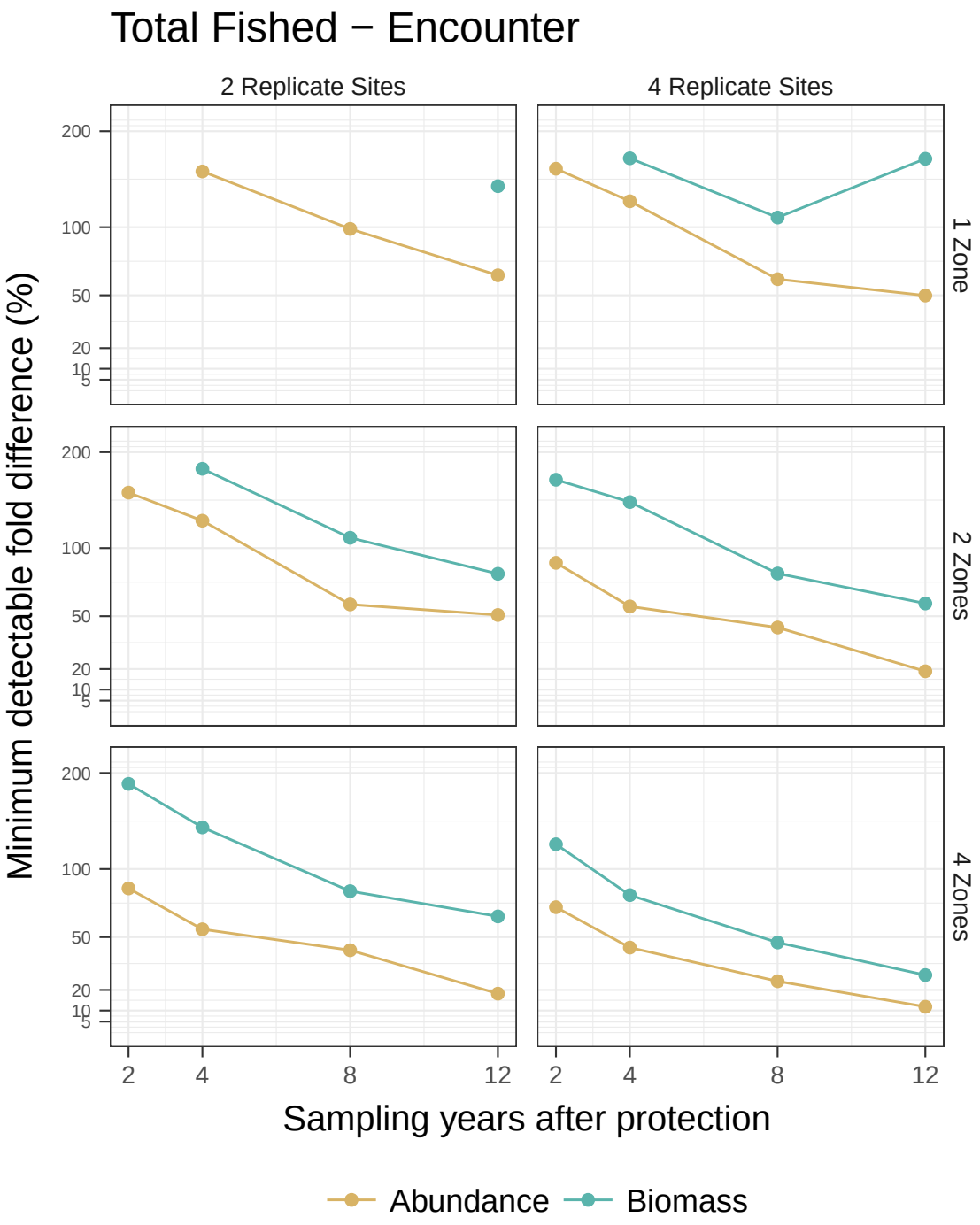

Figure 7. Minimum detectable fold differences (MDD; log scale) in total abundance and biomass of fished species in sanctuary zones in the Encounter Marine Park. MDD was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDD was calculated by linear interpolation between the simulated fold differences in abundance or biomass detectable with a power of 80%. Missing estimates of MDD for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDD for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDD was below 5% (the lowest annual fold difference used in the simulations) and the interpolation gave unrealistic estimates.

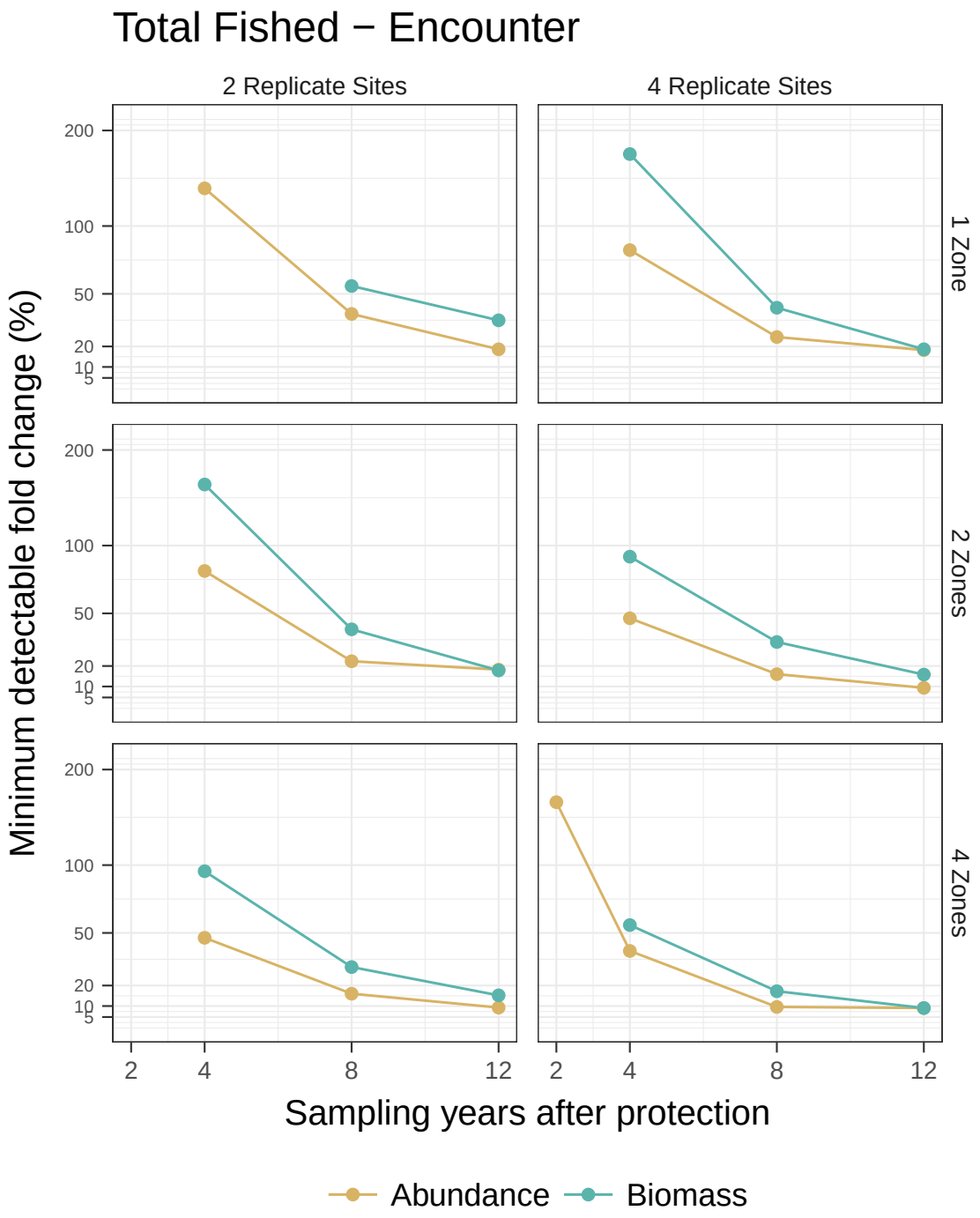

Figure 8. Minimum detectable linear fold changes (MDC; log scale) in total abundance and biomass of fished species in sanctuary zones in the Encounter Marine Park. MDC was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDC was calculated by linear interpolation between the simulated linear fold changes in abundance or biomass detectable with a power of 80%. Missing estimates of MDC for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design.

	Fished species Abundance
Intercept	4.95^*
	$[4.41;\ 5.48]$
Outside zone	-0.15
	$[-0.62;\ 0.32]$
R^2	0.65
Num. obs.	198
Num. groups: site.zone	76
Num. groups: yearf.zone	41
Num. groups: yearf	10
Num. groups: zone	7
Var: site.zone (Intercept)	0.59
ICC: site.zone	**0.33**
Var: yearf.zone (Intercept)	0.00
ICC: yearf.zone	**0.00**
Var: yearf (Intercept)	0.04
ICC: yearf	**0.02**
Var: zone (Intercept)	0.27
ICC: zone	**0.13**

* 0 outside the confidence interval

Table 1. Model summary table for Encounter MP fished species abundances. Generalised linear mixed models were used with Inside/Outside as a fixed effect and Sanctuary Zone, Site, and Year as random effects. 'Outside zone' shows the difference in mean (log) abundance outside versus inside MP zones; Values in square brackets are 95% confidence intervals; 'Var' is the variance component; 'ICC' is the intra-class correlation coefficient showing the strength of correlation between observations within grouping levels of the random effect.

	Fished species Biomass
Intercept	2.17^*
	$[1.69;\ 2.65]$
Outside zone	-0.27
	$[-0.63;\ 0.10]$
R^2	0.65
Num. obs.	198
Num. groups: zone	7
Num. groups: site.zone	76
Num. groups: yearf	10
Num. groups: yearf.zone	41
Var: zone	0.18
ICC: zone	**0.18**
Var: site.zone	0.32
ICC: site.zone	**0.31**
Var: yearf	0.11
ICC: yearf	**0.11**
Var: yearf.zone	0.05
ICC: yearf.zone	**0.05**

* 0 outside the confidence interval

Table 2. Model summary tables for Encounter MP fished species biomass. Generalised linear mixed models were used with Inside/Outside as a fixed effect and Sanctuary Zone, Site, and Year as random effects. 'Outside zone' shows the difference in mean (log) biomass outside versus inside MP zones; Values in square brackets are 95% confidence intervals; 'Var' is the variance component; 'ICC' is the intra-class correlation coefficient showing the strength of correlation between observations within grouping levels of the random effect.

5.2 Integrated Summary: Minimum detectable changes in Indicator species in Encounter MP

5.2.1 Abundance of indicator fish and invertebrate species

The average abundances of the four fish and three invertebrate indicator species inside sanctuary zones were similar to outside the zones (Figure 9; Table 3). The largest components of variation was between sanctuary zones for the fish species, except sweep, and for blacklip abalone. Variation in abundance between sites at a sanctuary zone was highest for the remaining three species. Generally, variation among years was relatively lower for all these species (Table 3).

Among the fish species, only bluethroat wrasse and sweep gave average minimum detectable increases of 200% (i.e., a factor of 3) or less inside sanctuary zones for most sampling scenarios (Figure 10). Average increases of 50% could be detected after four years of protection when two or more sanctuary zones were sampled at four sites inside and outside the zones for bluethrout wrasse, whereas eight years of sampling under the same design was needed to reliably detect such increases for sweep (Figure 10 - centre- and lower-right).

Similar sizes of detectable differences to those estimated for bluethroat wrasse were evident for blacklip abalone (Figure 11). Differences inside sanctuary zones of much greater than 200% were required for detection for greenlip abalone or rock lobster, although rock lobster abundances that were twice as large inside sanctuaries were detectable after 8-12 years of sampling for the highest intensity spatial sampling design (Figure 11 - lower-right).

A similar picture emerged for detecting linear trends in abundance of the indicator species. In the high intensity spatial sampling designs, annual increases of approximately 20% were detectable for bluethroat wrasse and sweep, and these decreased to around 10% after 12 years of sampling for the four zones and four sites scenario (Figure 12 - centre-, lower-left and lower-right). Blacklip abalone trends of 20% could be detected under these same scenarios (again similar sized effects to bluethroat wrasse), and rock lobster trends also became detectable (Figure 13 - centre-, lower-left and lower-right).

The precision of detectable trends was another potentially useful measure of suitability of an indicator species, and these estimates highlight that blue groper, harlequin fish, greenlip abalone, and rock lobster trends were imprecise under most, if not all, sampling scenarios examined (Figures 24, 25, 26, and 27).

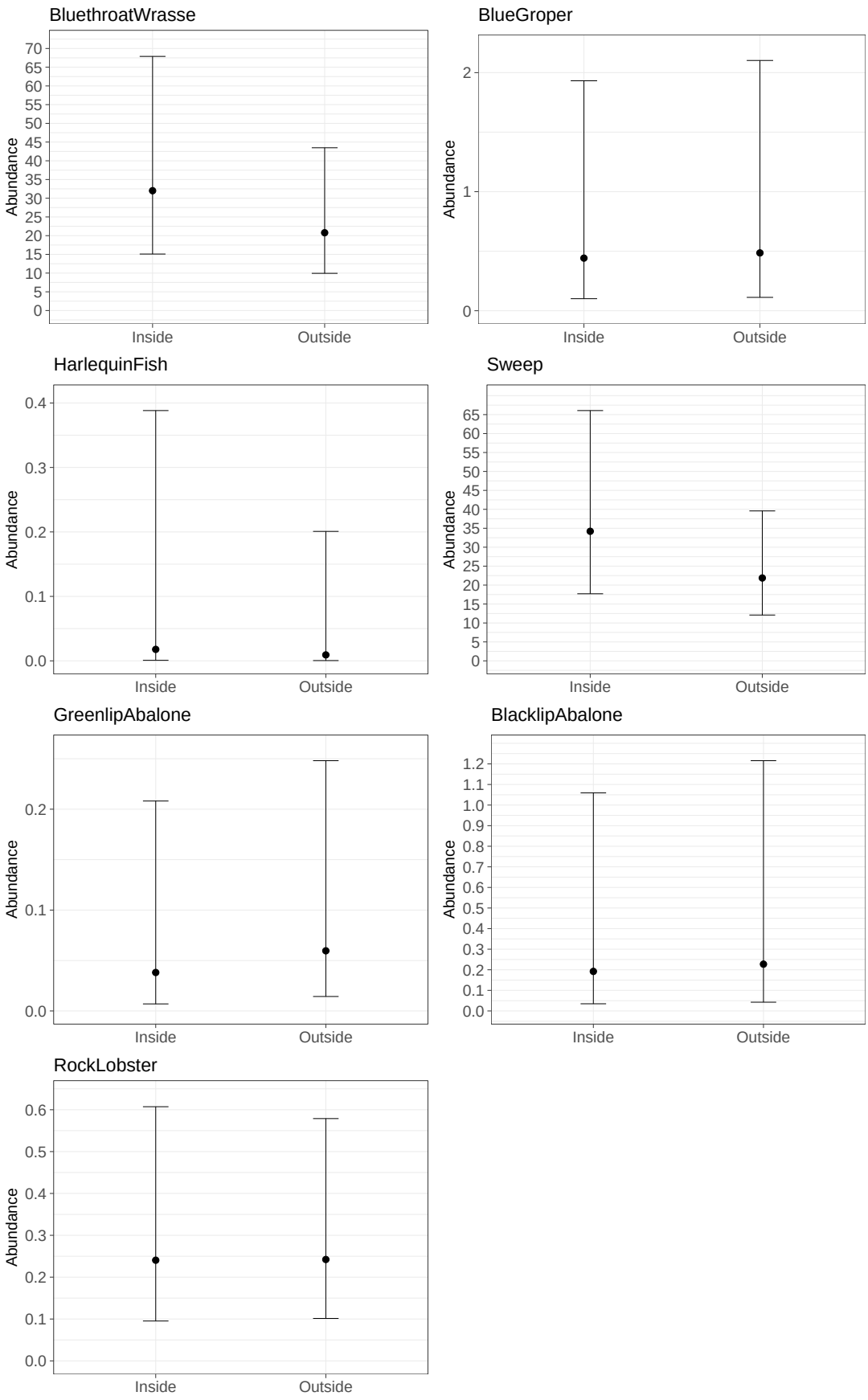

Figure 9. Estimated mean abundance of indicator species Inside and Outside of sanctuary zones in the Encounter Marine Park. Error bars are 95% confidence intervals.

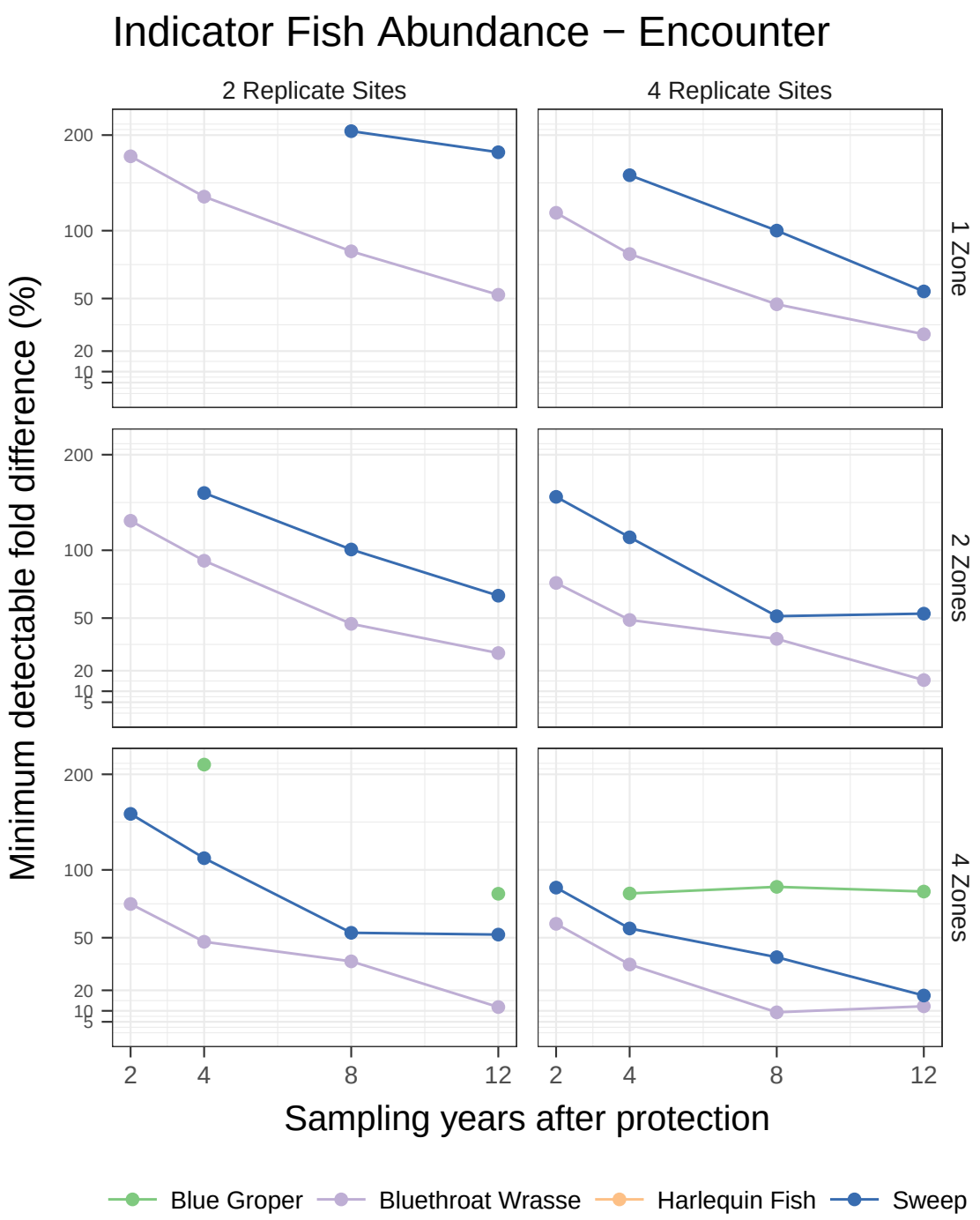

Figure 10. Minimum detectable linear fold differences (MDD; log scale) in abundance of fish indicator species in sanctuary zones in the Encounter Marine Park. MDD was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDD was calculated by linear interpolation between the simulated linear fold differences in abundance detectable with a power of 80%. Missing estimates of MDD for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDD for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDD was below 5% (the lowest annual fold change used in the simulations) and the interpolation gave unrealistic estimates.

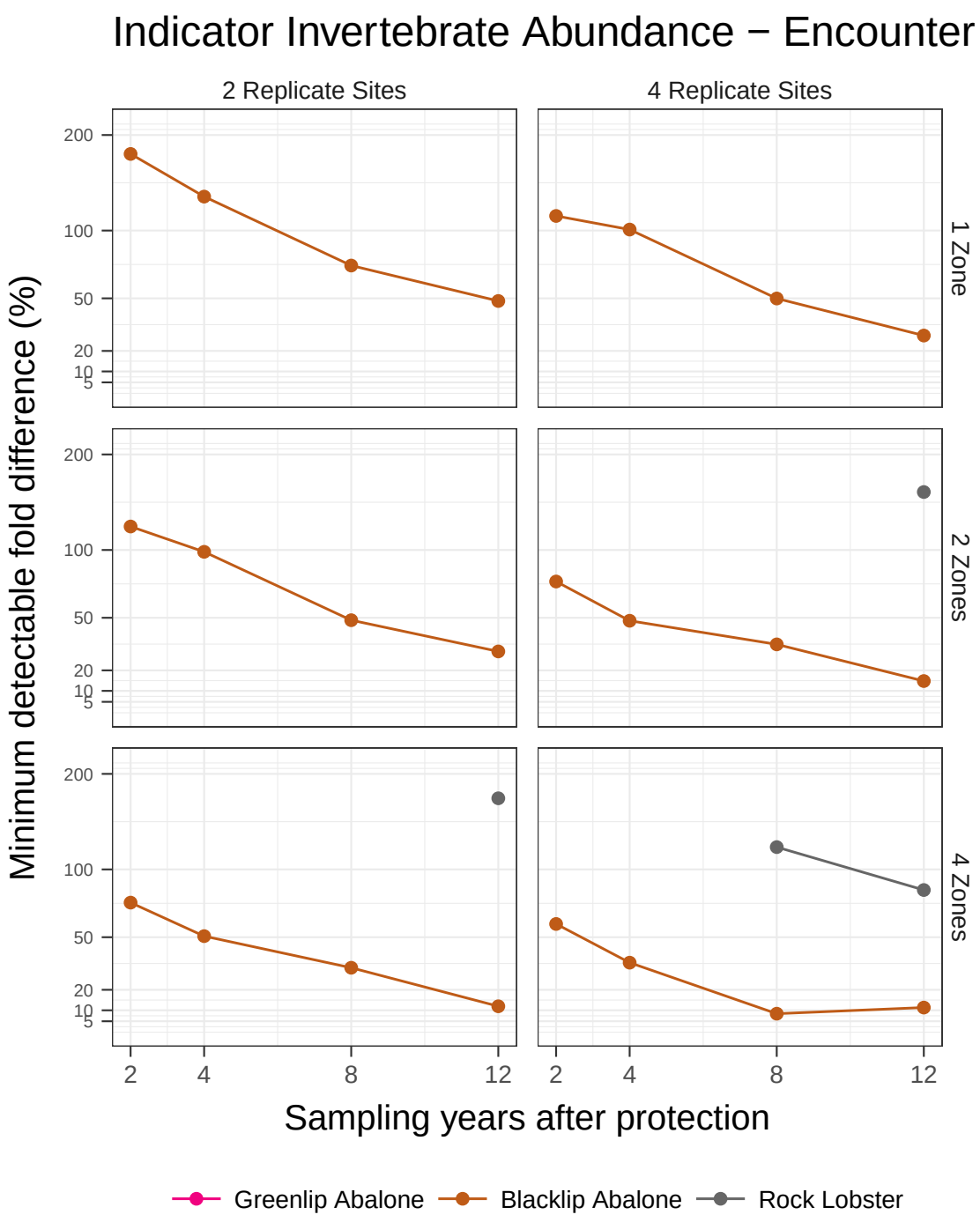

Figure 11. Minimum detectable linear fold differences (MDD; log scale) in abundance of invertebrate indicator species in sanctuary zones in the Encounter Marine Park. MDD was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDD was calculated by linear interpolation between the simulated linear fold differences in abundance detectable with a power of 80%. Missing estimates of MDD for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDD for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDD was below 5% (the lowest annual fold change used in the simulations) and the interpolation gave unrealistic estimates.

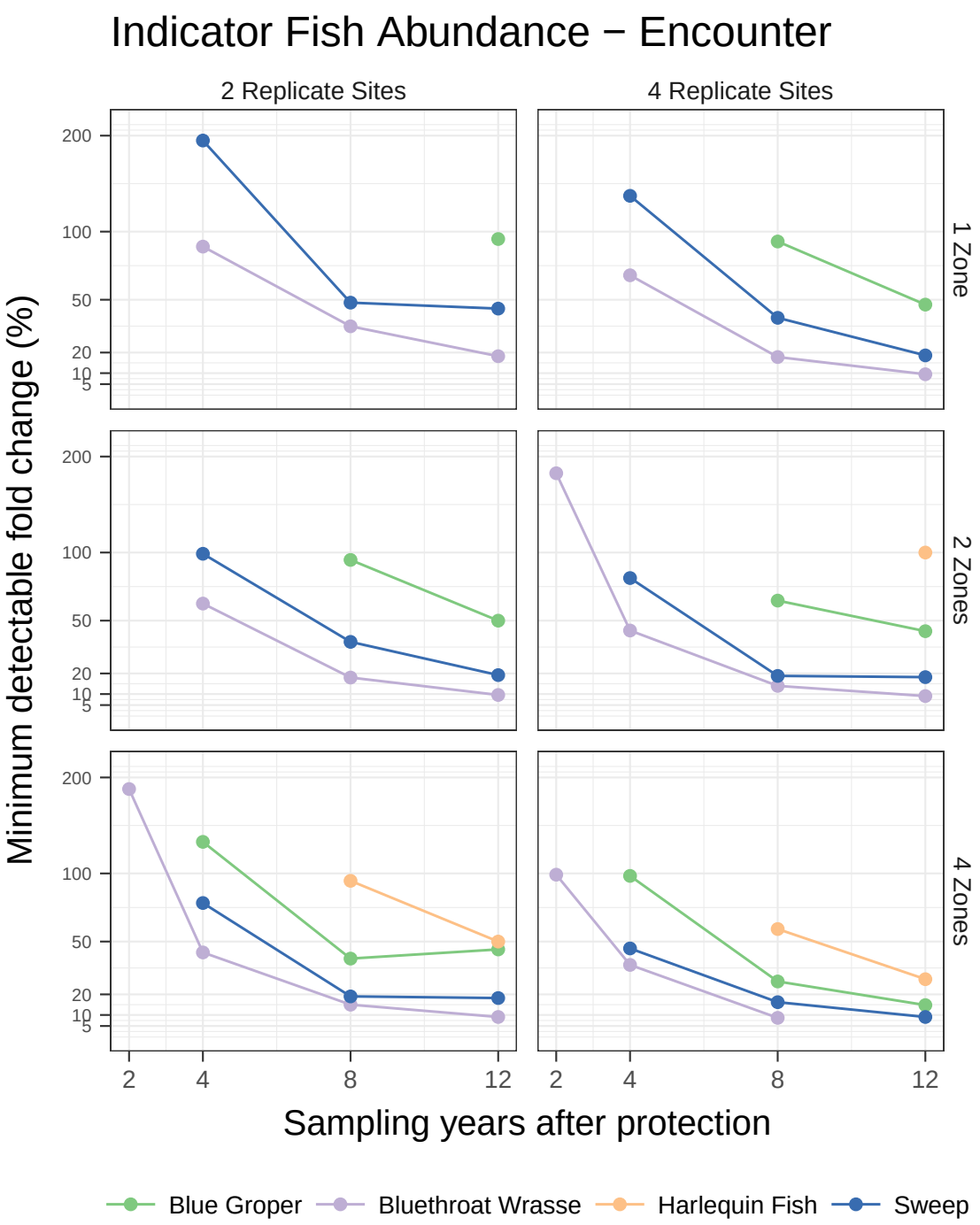

Figure 12. Minimum detectable linear fold changes (MDC; log scale) in abundance of fish indicator species in sanctuary zones in the Encounter Marine Park. MDC was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDC was calculated by linear interpolation between the simulated linear fold changes in abundance detectable with a power of 80%. Missing estimates of MDC for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDC for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDC was below 5% (the lowest annual fold change used in the simulations) and the interpolation gave unrealistic estimates.

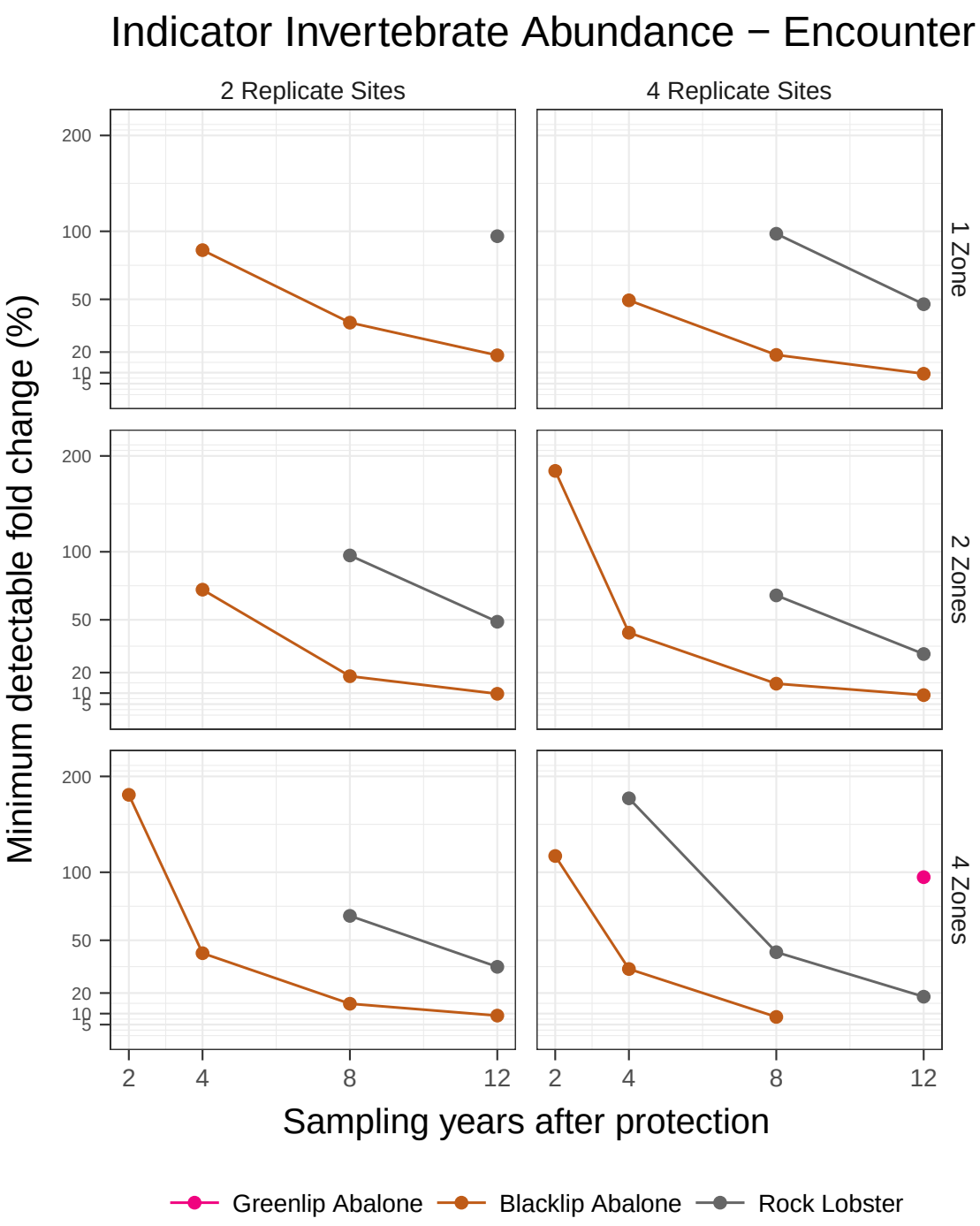

Figure 13. Minimum detectable linear fold changes (MDC; log scale) in abundance of invertebrate indicator species in sanctuary zones in the Encounter Marine Park. MDC was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDC was calculated by linear interpolation between the simulated linear fold changes in abundance detectable with a power of 80%. Missing estimates of MDC for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDC for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDC was below 5% (the lowest annual fold change used in the simulations) and the interpolation gave unrealistic estimates.

	BlueGroper	BluethroatWrasse	HarlequinFish	Sweep	GreenlipAbalone	BlacklipAbalone	RockLobster
Intercept	-2.14^*	2.14^*	-5.36^*	2.20^*	-4.59^*	-2.98^*	-2.75^*
	$[-3.62;\ -0.67]$	$[1.39;\ 2.89]$	$[-8.44;\ -2.27]$	$[1.55;\ 2.86]$	$[-6.29;\ -2.90]$	$[-4.68;\ -1.27]$	$[-3.68;\ -1.83]$
Outside zone	0.09	-0.43	-0.66	-0.45	0.45	0.17	0.01
	$[-0.41;\ 0.60]$	$[-0.78;\ 0.09]$	$[-1.30;\ 0.02]$	$[-1.02;\ 0.13]$	$[-0.86;\ 1.76]$	$[-0.74;\ 1.07]$	$[-0.66;\ 0.67]$
R^2	0.80	0.81	0.41	0.61	0.11	0.83	0.27
Num. obs.	194	194	194	194	194	194	194
Num. groups: site.zone	75	75	75	75	75	75	75
Num. groups: yearf.zone	40	40	40	40	40	40	40
Num. groups: yearf	10	10	10	10	10	10	10
Num. groups: zone	7	7	7	7	7	7	7
Var: site.zone (Intercept)	0.17	0.24	0.00	0.80	1.37	1.15	0.63
ICC: site.zone	**0.00**	**0.07**	**0.00**	**0.25**	**0.07**	**0.01**	**0.08**
Var: yearf.zone (Intercept)	0.10	0.03	0.10	0.00	0.11	0.74	0.00
ICC: yearf.zone	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Var: yearf (Intercept)	1.26	0.24	0.00	0.19	0.47	0.75	0.41
ICC: yearf	**0.03**	**0.08**	**0.00**	**0.04**	**0.01**	**0.00**	**0.05**
Var: zone (Intercept)	2.62	0.77	6.57	0.30	1.04	2.99	0.40
ICC: zone	**0.14**	**0.33**	**0.65**	**0.07**	**0.04**	**0.05**	**0.04**

* 0 outside the confidence interval

Table 3. Model summary tables for Encounter MP indicator species abundances. Generalised linear mixed models were used with Inside/Outside as a fixed effect and Sanctuary Zone, Site, and Year as random effects. 'Outside zone' shows the difference in mean (log) abundance outside versus inside MP zones; Values in square brackets are 95% confidence intervals; 'Var' is the variance component; 'ICC' is the intra-class correlation coefficient showing the strength of correlation between observations within grouping levels of the random effect.

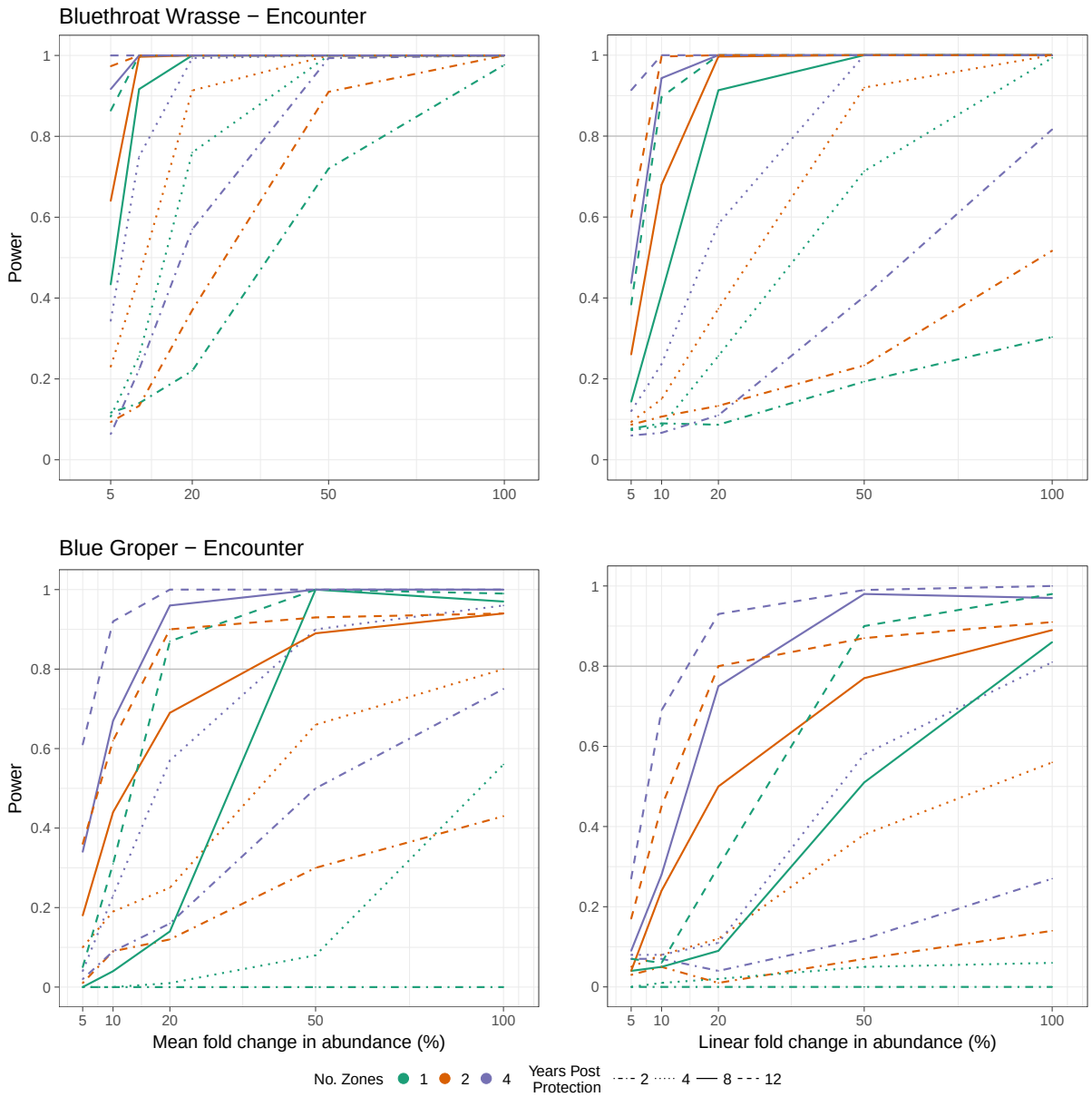

Figure 14. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in abundance of bluethroat wrasse (upper row) and blue groper (lower row) for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

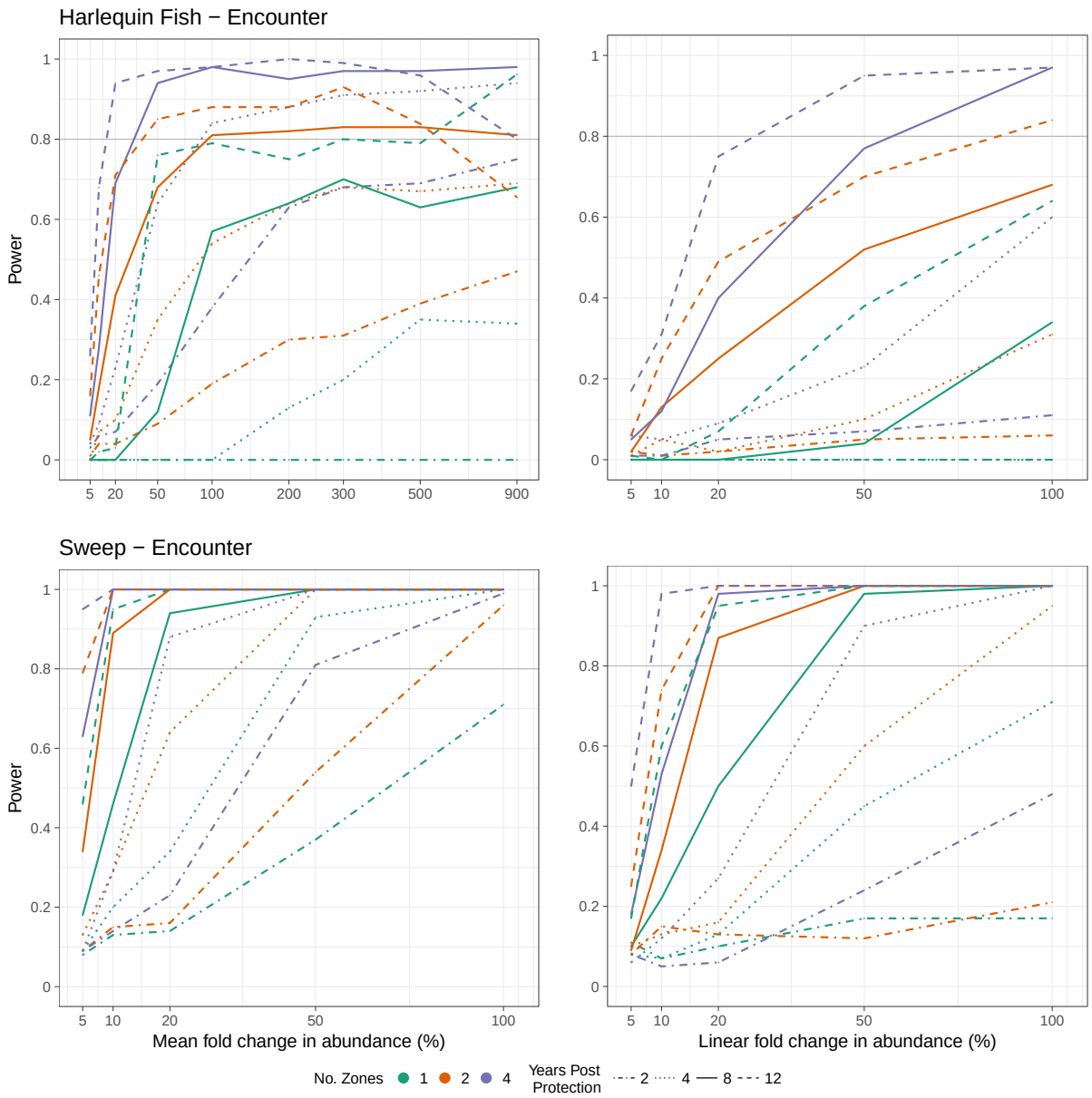

Figure 15. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in abundance of harlequin fish (upper row) and sweep (lower row) for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

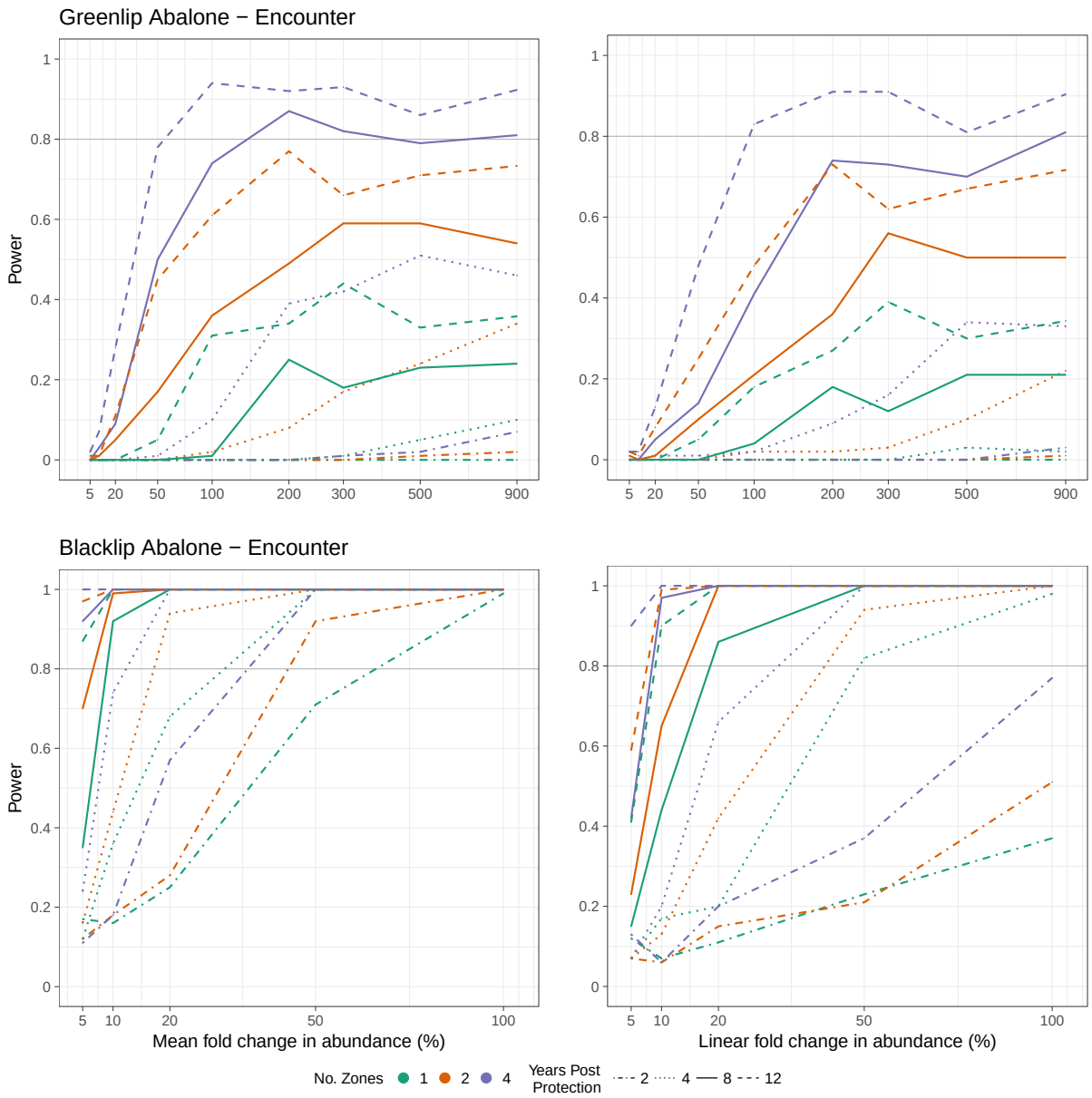

Figure 16. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in abundance of greenlip abalone (upper row) and blacklip abalone (lower row) for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

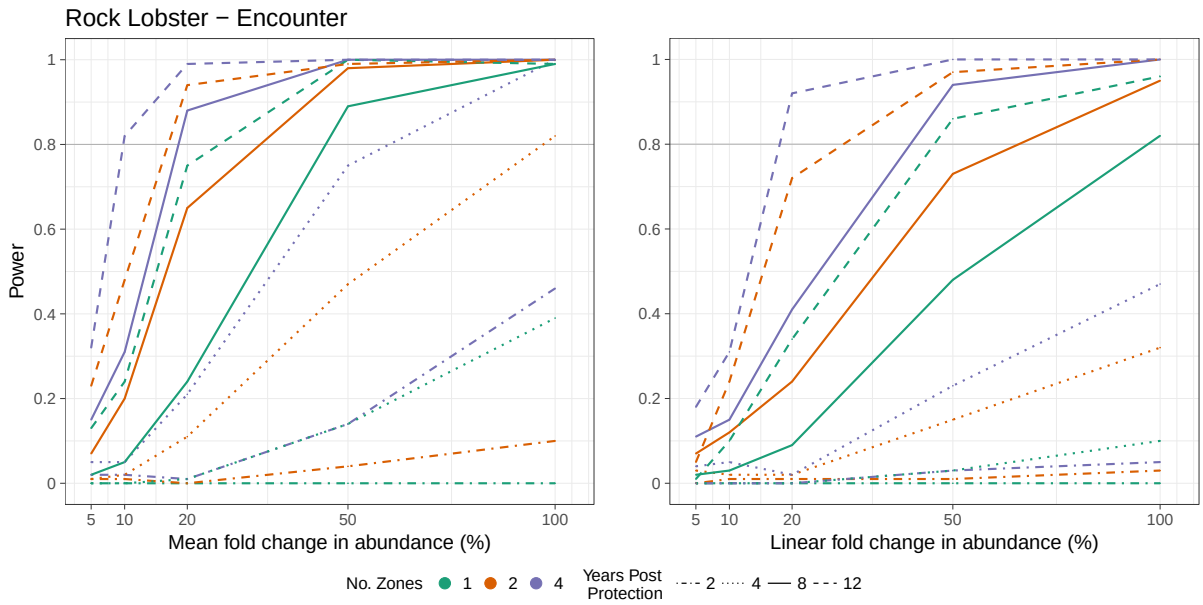

Figure 17. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in abundance of rock lobster for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

5.2.2 Biomass of indicator fish and invertebrate species

The average biomass of the four fish indicator species inside sanctuary zones were similar to outside the zones (Figure 18; Table 4). The largest components of variation was between sanctuary zones for the blue groper and sweep, and variation between sites at a sanctuary zone was highest for bluethroat wrasse and harlequin fish species. Generally, variation among years was relatively lower for all these species (Table 4).

Detectable biomass differences inside sanctuary zones for the indicator fish species were generally much higher than would be required from useful indicators (Figure 19), and the smallest detectable trends were greater than 20% in all scenarios across all species, except for bluethroat wrasse and sweep in the highest sampling intensity scenario (Figure 20 - lower-right).

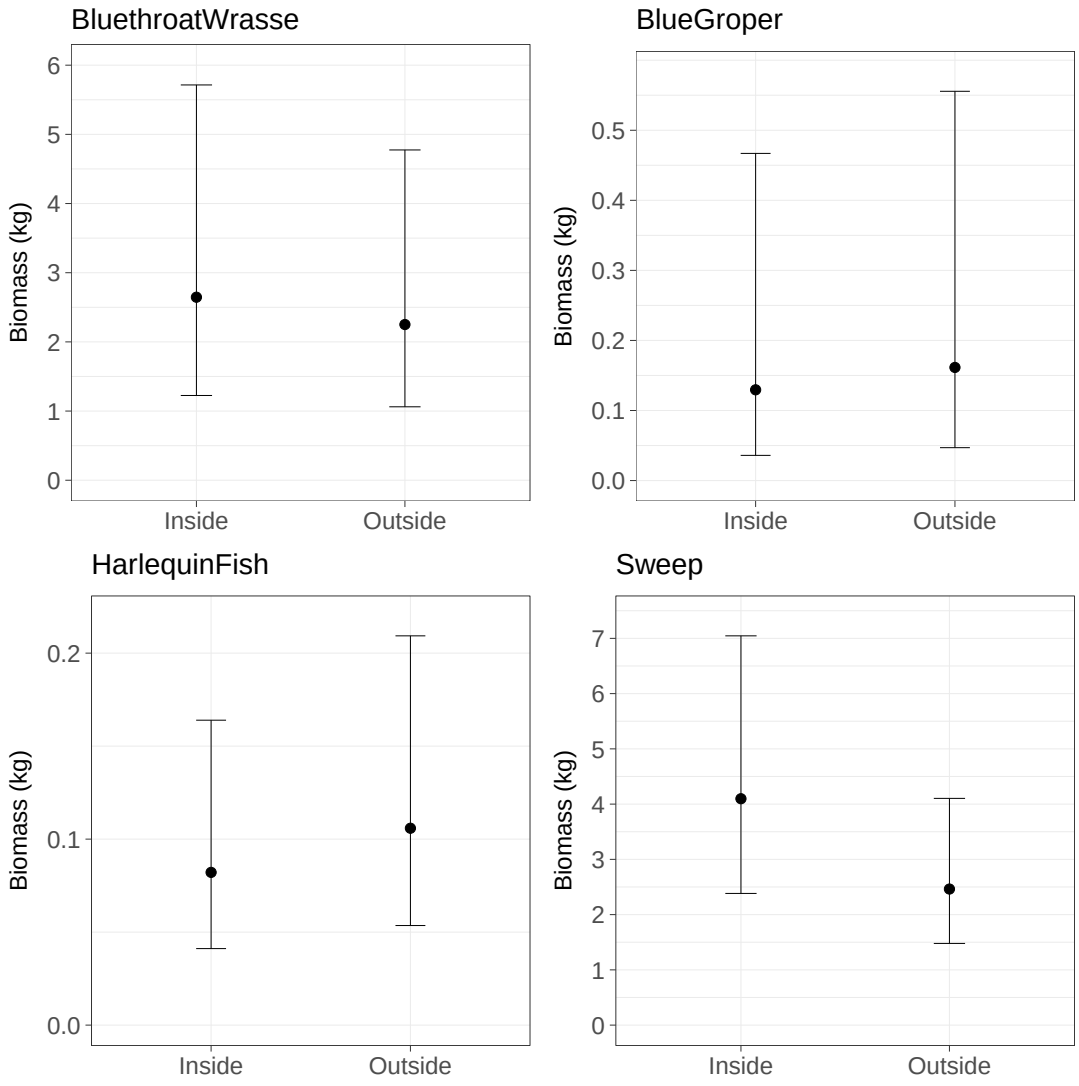

Figure 18. Estimated mean biomass of indicator species Inside and Outside of sanctuary zones in the Encounter Marine Park. Error bars are 95% confidence intervals.

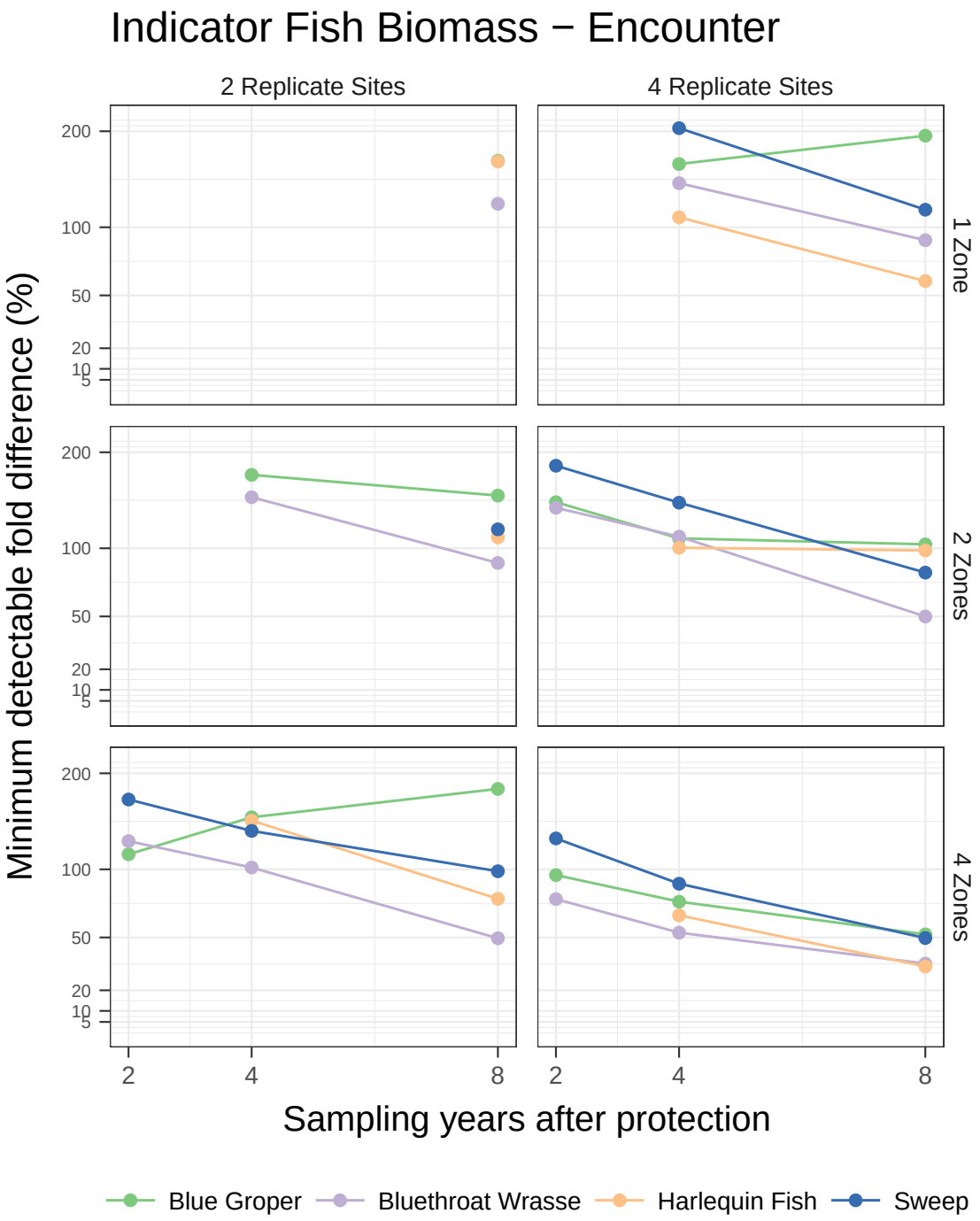

Figure 19. Minimum detectable linear fold differences (MDD; log scale) in biomass of fish indicator species in sanctuary zones in the Encounter Marine Park. MDD was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDD was calculated by linear interpolation between the simulated linear fold differences in biomass detectable with a power of 80%. Missing estimates of MDD for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDD for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDD was below 5% (the lowest annual fold change used in the simulations) and the interpolation gave unrealistic estimates.

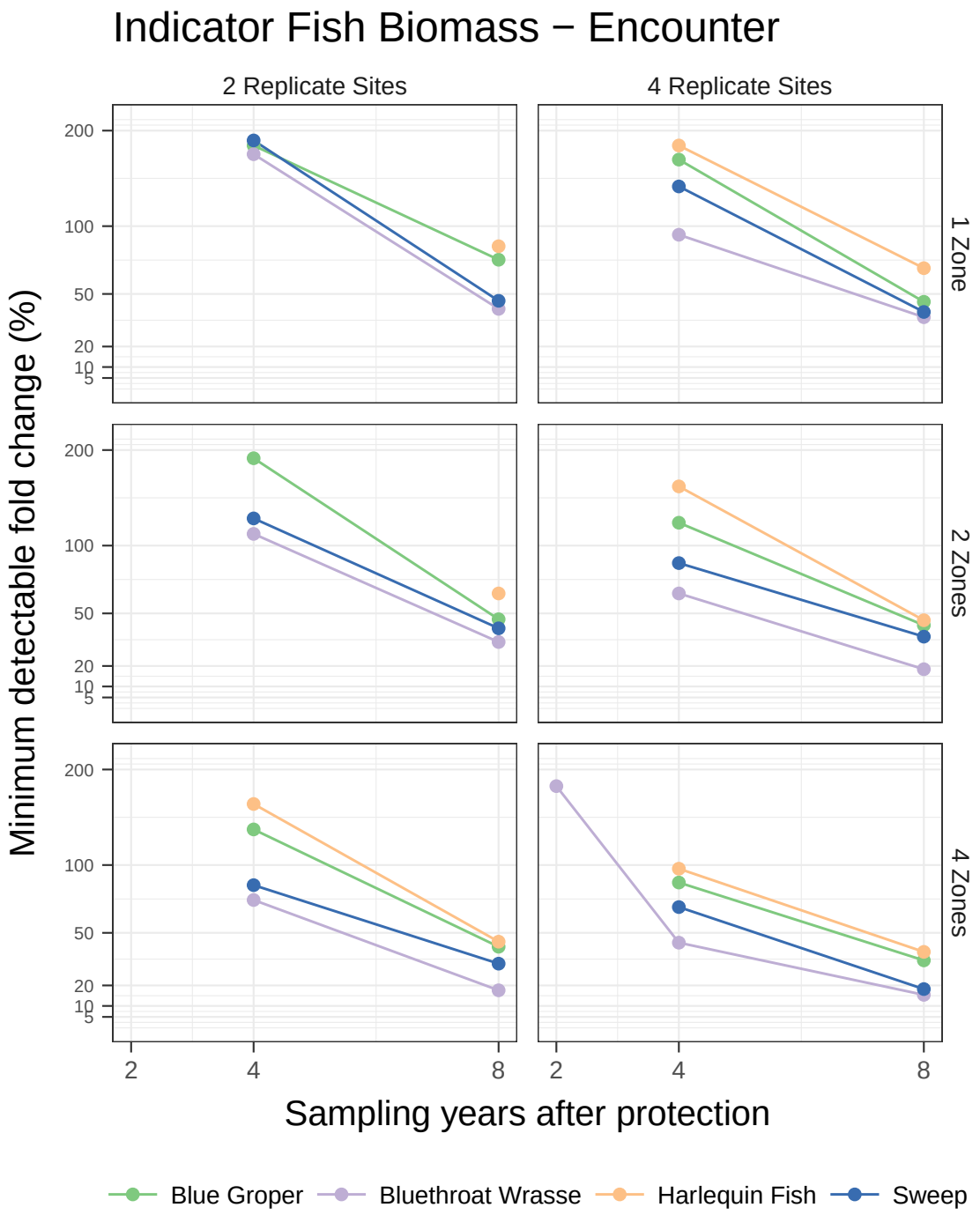

Figure 20. Minimum detectable linear fold changes (MDC; log scale) in biomass of fish indicator species in sanctuary zones in the Encounter Marine Park. MDC was estimated for 2-12 years of sampling post-protection for each combination of Zone (1, 2, or 4) and Site within Zone (2, or 4) replication. MDC was calculated by linear interpolation between the simulated linear fold changes in biomass detectable with a power of 80%. Missing estimates of MDC for certain combinations of Zone and Site replication for a given number of years of post-protection sampling indicate that 80% power was not achievable for that sampling design. Missing estimates of MDC for 12 years post-protection sampling, where estimates in the shorter term are available indicate that MDC was below 5% (the lowest annual fold change used in the simulations) and the interpolation gave unrealistic estimates.

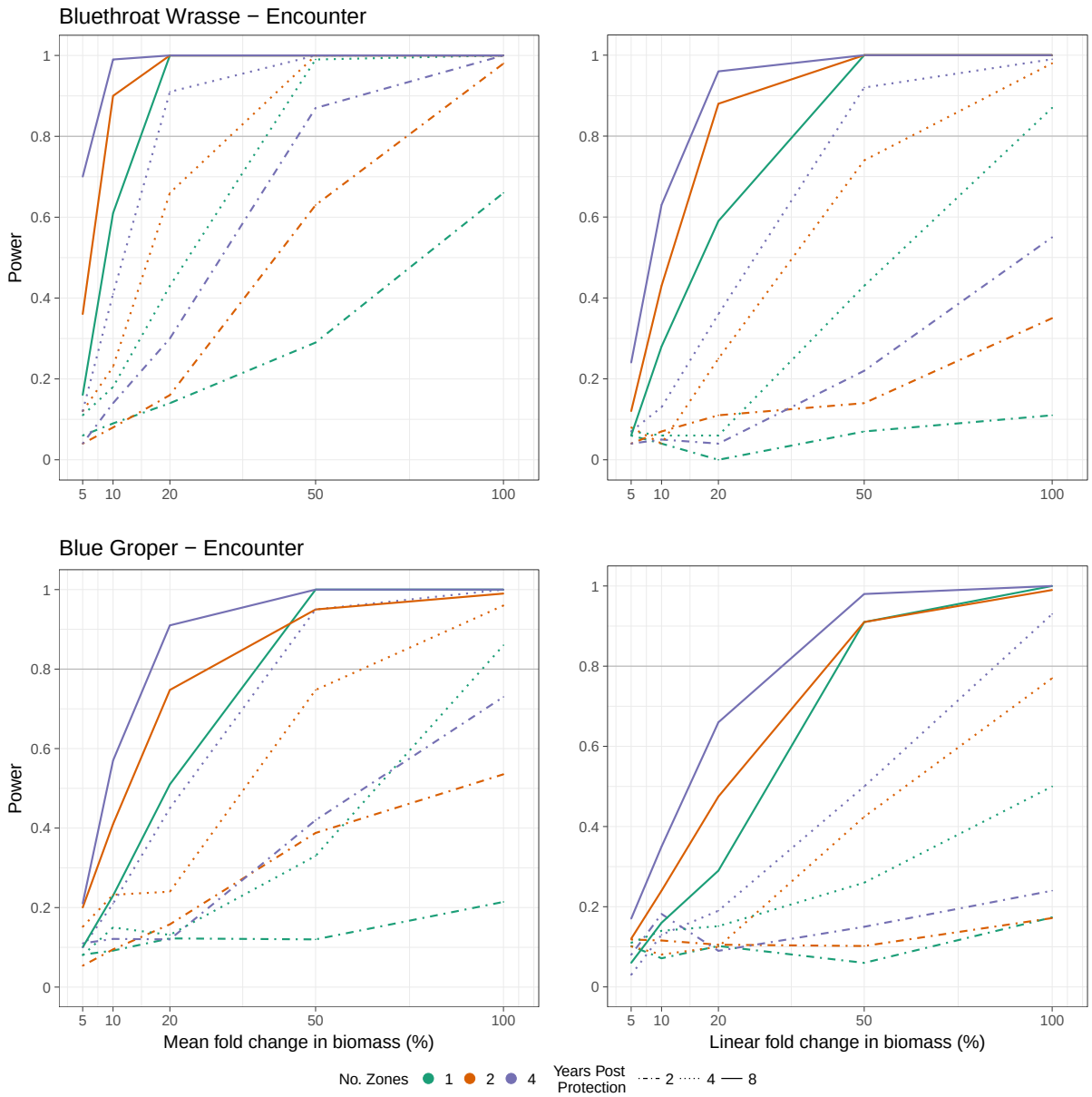

Figure 21. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in biomass of bluethroat wrasse (upper row) and blue groper (lower row) for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

	BlueGroper	BluethroatWrasse	HarlequinFish	Sweep
Intercept	-3.37^*	-0.35	-2.49^*	0.08
	$[-4.65;\ -2.09]$	$[-1.12;\ 0.42]$	$[-2.49;\ -2.48]$	$[-0.46;\ 0.62]$
Outside zone	0.22	-0.16	-0.22	-0.51
	$[-0.50;\ 0.94]$	$[-0.67;\ 0.34]$	$[-0.22;\ 0.22]$	$[-0.90;\ 0.11]$
R^2	0.68	0.65	0.46	0.21
Num. obs.	194	194	194	194
Num. groups: site.zone	75	75	75	
Num. groups: yearf	10	10		10
Num. groups: zone	7	7		7
Num. groups: yearf.zone		40		
Var: site.zone (Intercept)	1.96	0.36	0.37	
ICC: site.zone	**0.28**	**0.33**	**0.50**	
Var: yearf (Intercept)	0.32	0.01		0.00
ICC: yearf	**0.05**	**0.01**		**0.00**
Var: zone (Intercept)	3.29	0.28		0.41
ICC: zone	**0.48**	**0.25**		**0.28**
Var: yearf.zone (Intercept)		0.11		
ICC: yearf.zone		**0.10**		
Var: Residual	1.35	0.35	0.37	1.03

* 0 outside the confidence interval

Table 4. Model summary tables for Encounter MP indicator species biomass. Generalised linear mixed models were used with Inside/Outside as a fixed effect and Sanctuary Zone, Site, and Year as random effects. 'Outside zone' shows the difference in mean (log) biomass outside versus inside MP zones; Values in square brackets are 95% confidence intervals; 'Var' is the variance component; 'ICC' is the intra-class correlation coefficient showing the strength of correlation between observations within grouping levels of the random effect.

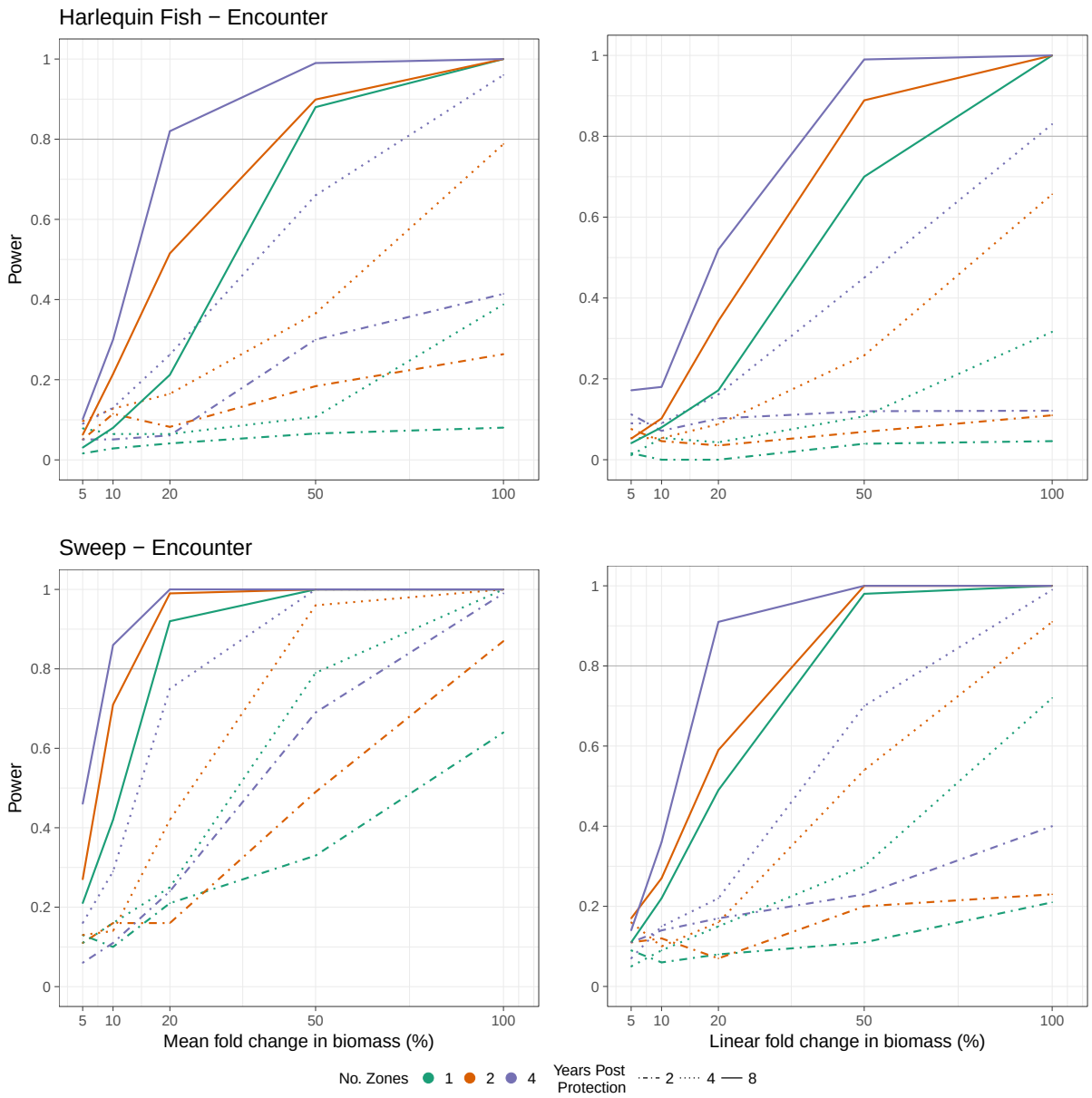

Figure 22. Power of mean fold changes (left column) and linear fold changes (i.e., trends; right column) in biomass of harlequin fish (upper row) and sweep (lower row) for simulated changes from 5% (1.05 fold change) up to 100% (2-fold change). Colour shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8.

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7 Supplementary Material

7.1 Fished species - Encounter MP

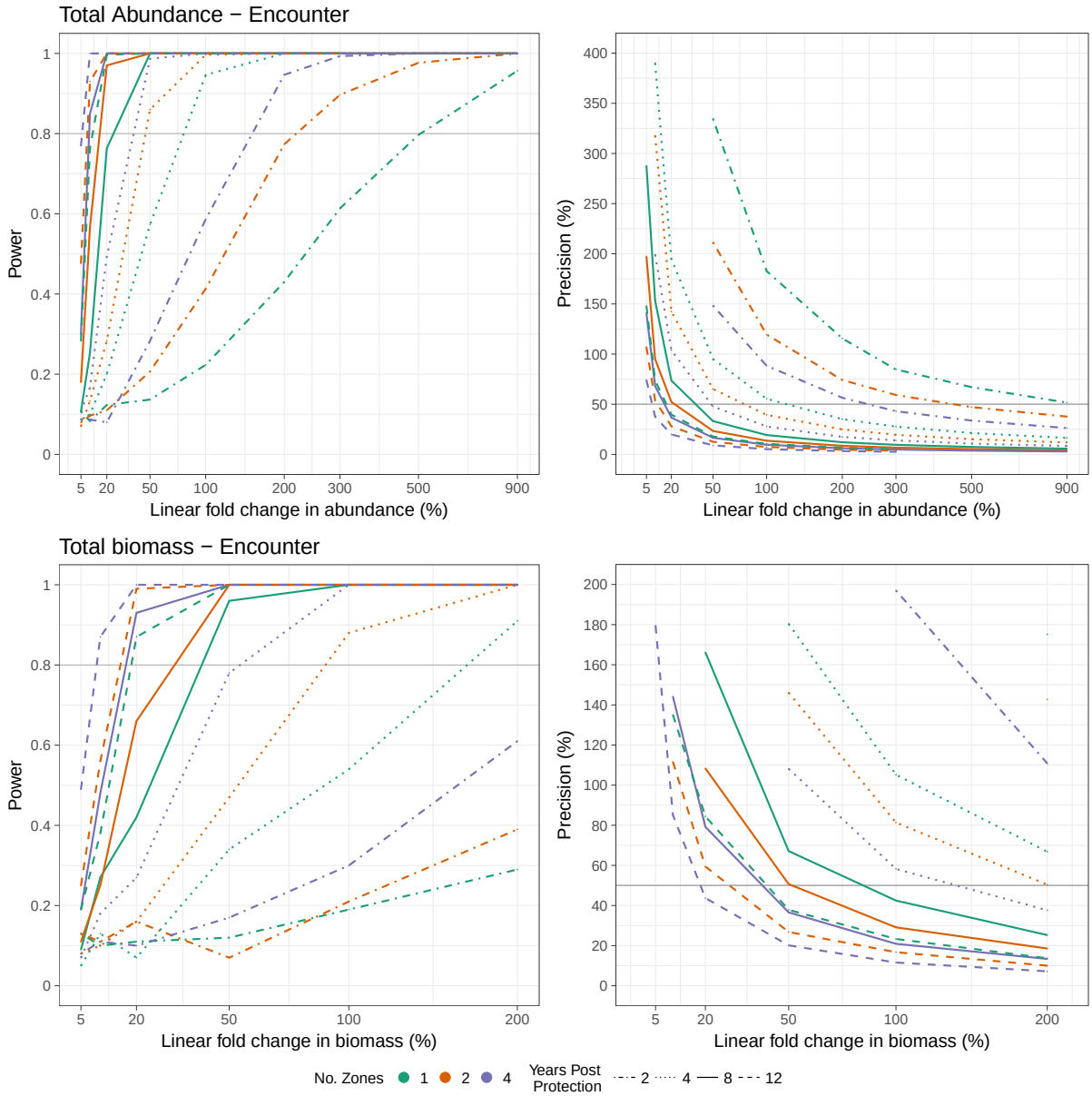

Figure 23. Power and precision of estimates of linear trends in total abundance (upper row) and biomass (lower row) for simulated fold changes from 5% (1.05 fold change) up to 900% (10 fold change - for abundance). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

7.2 Indicator species abundance - Encounter MP

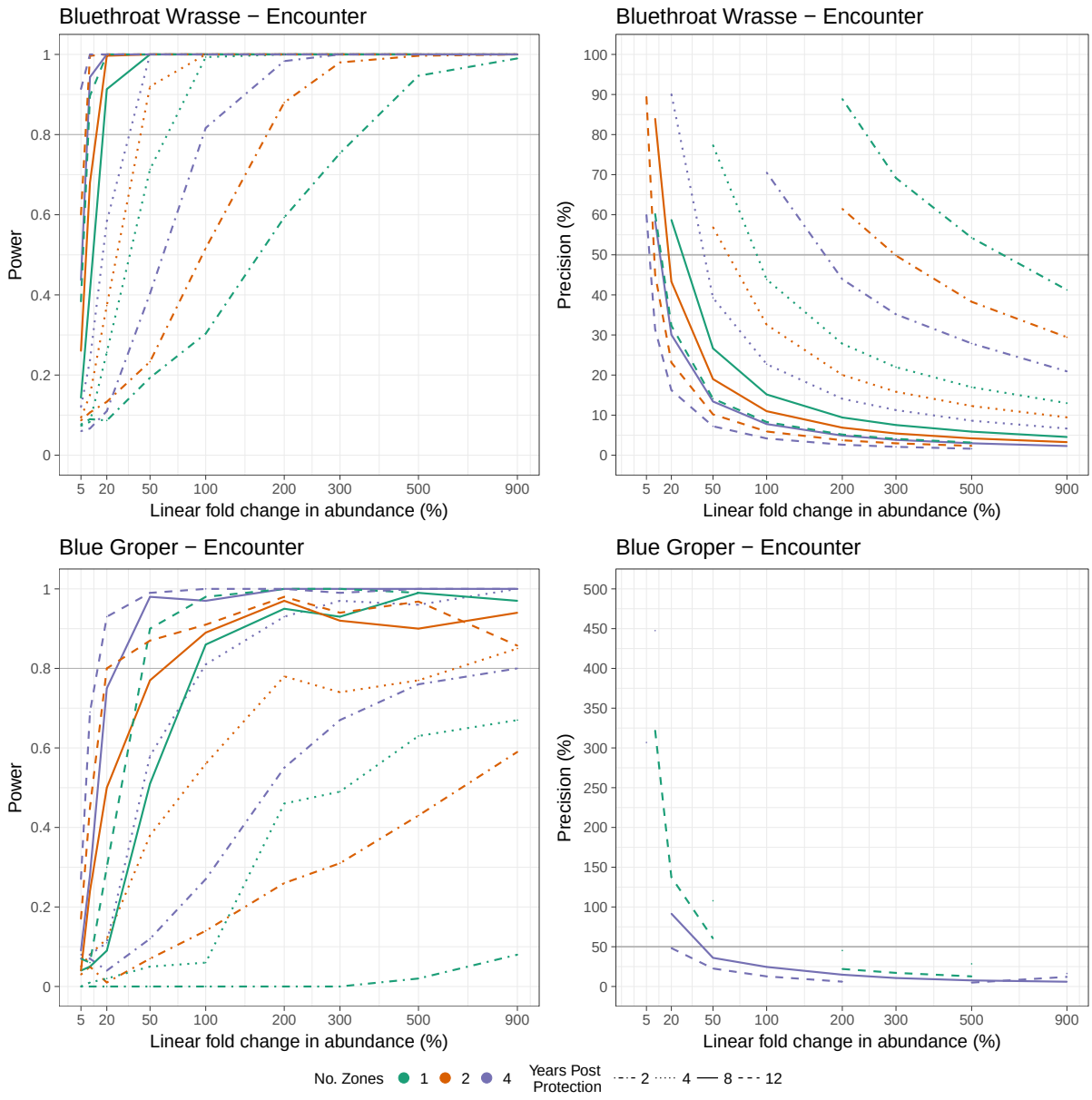

Figure 24. Power and precision of estimates of linear trends in abundance of Bluethroat Wrasse (upper row) and Blue Groper (lower row) for simulated fold changes from 5% (1.05 fold change) up to 900% (10 fold change). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

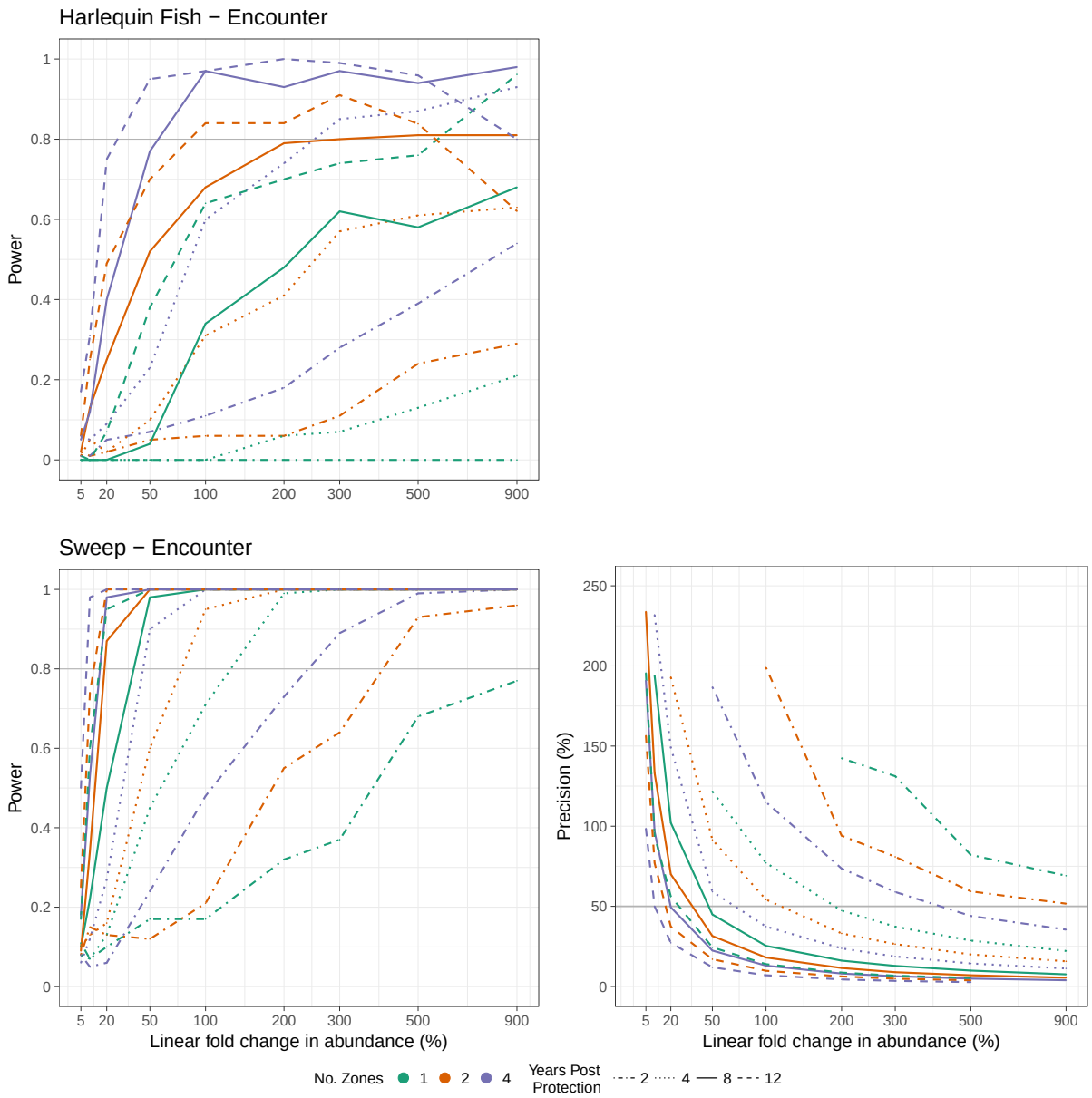

Figure 25. Power and precision of estimates of linear trends in abundance of Harlequin Fish (upper row) and Sweep (lower row) for simulated fold changes from 5% (1.05 fold change) up to 900% (10 fold change). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

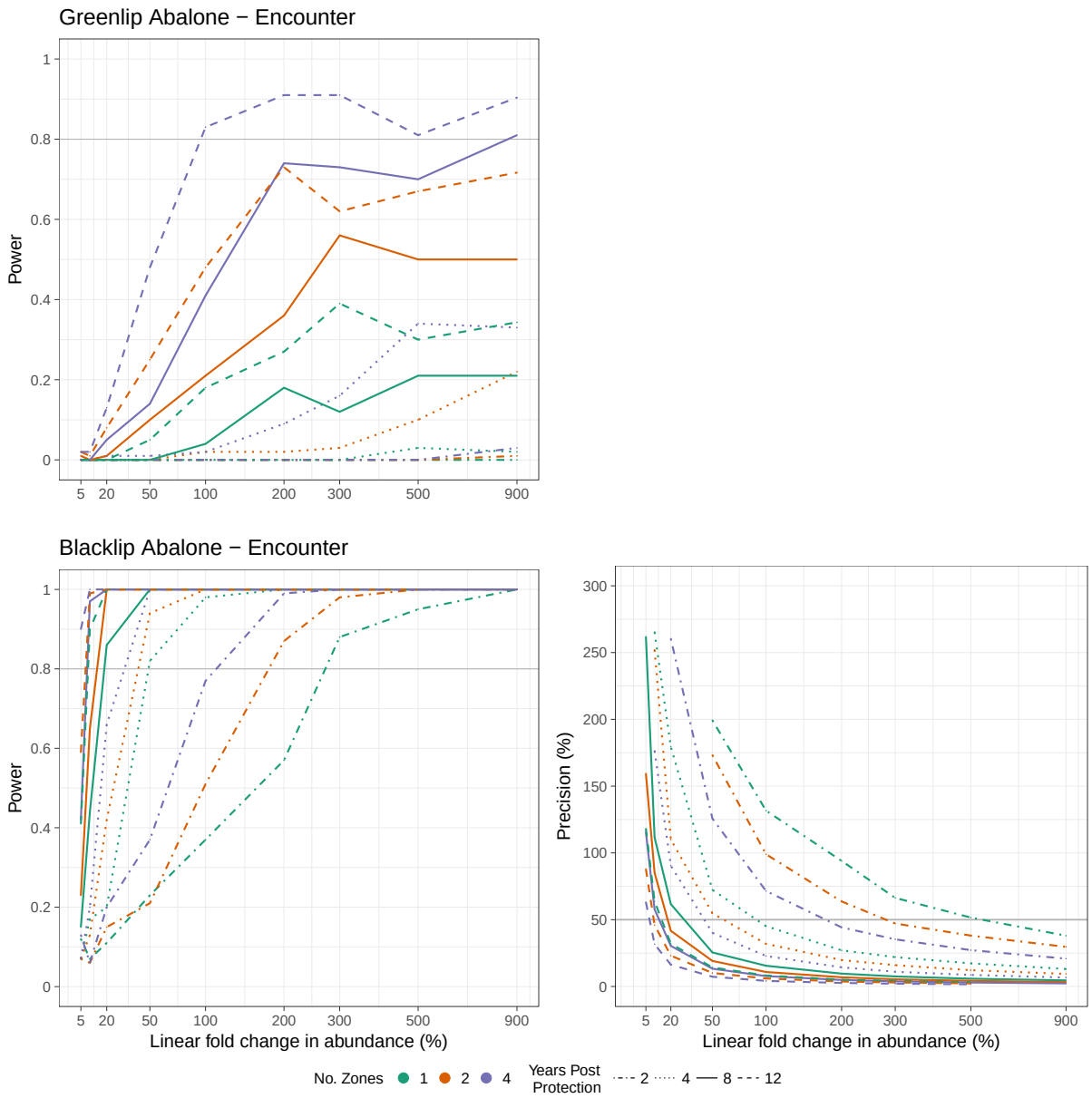

Figure 26. Power and precision of estimates of linear trends in abundance of Greenlip Abalone (upper row) and Blacklip Abalone (lower row) for simulated fold changes from 5% (1.05 fold change) up to 900% (10 fold change). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

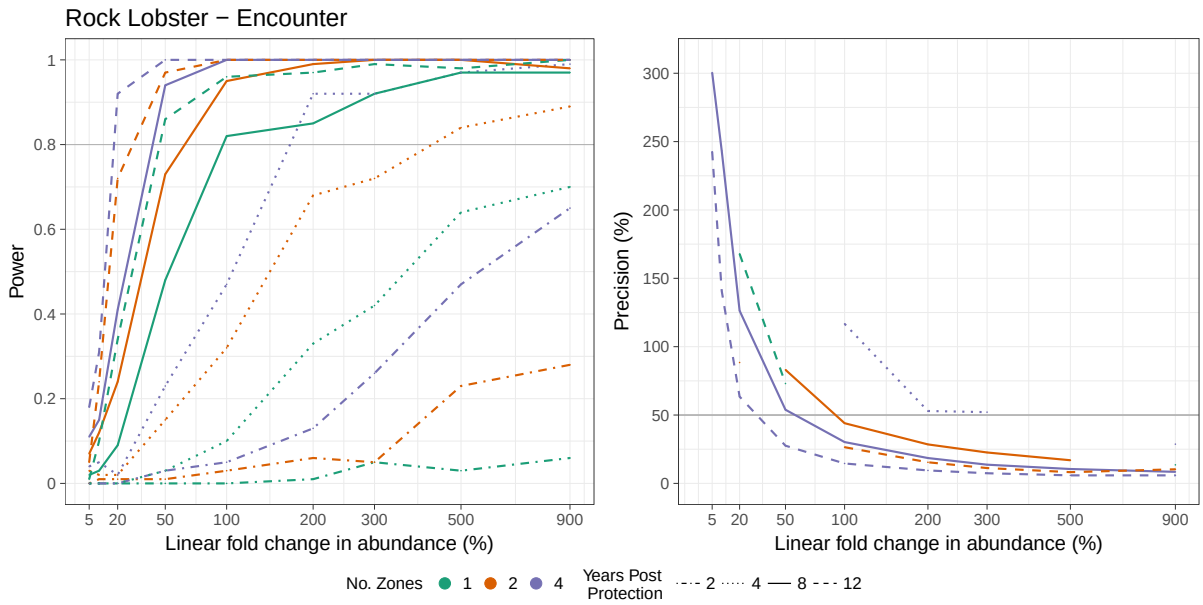

Figure 27. Power and precision of estimates of linear trends in abundance of Rock Lobster for simulated fold changes from 5% (1.05 fold change) up to 900% (10 fold change). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

7.3 Indicator species biomass - Encounter MP

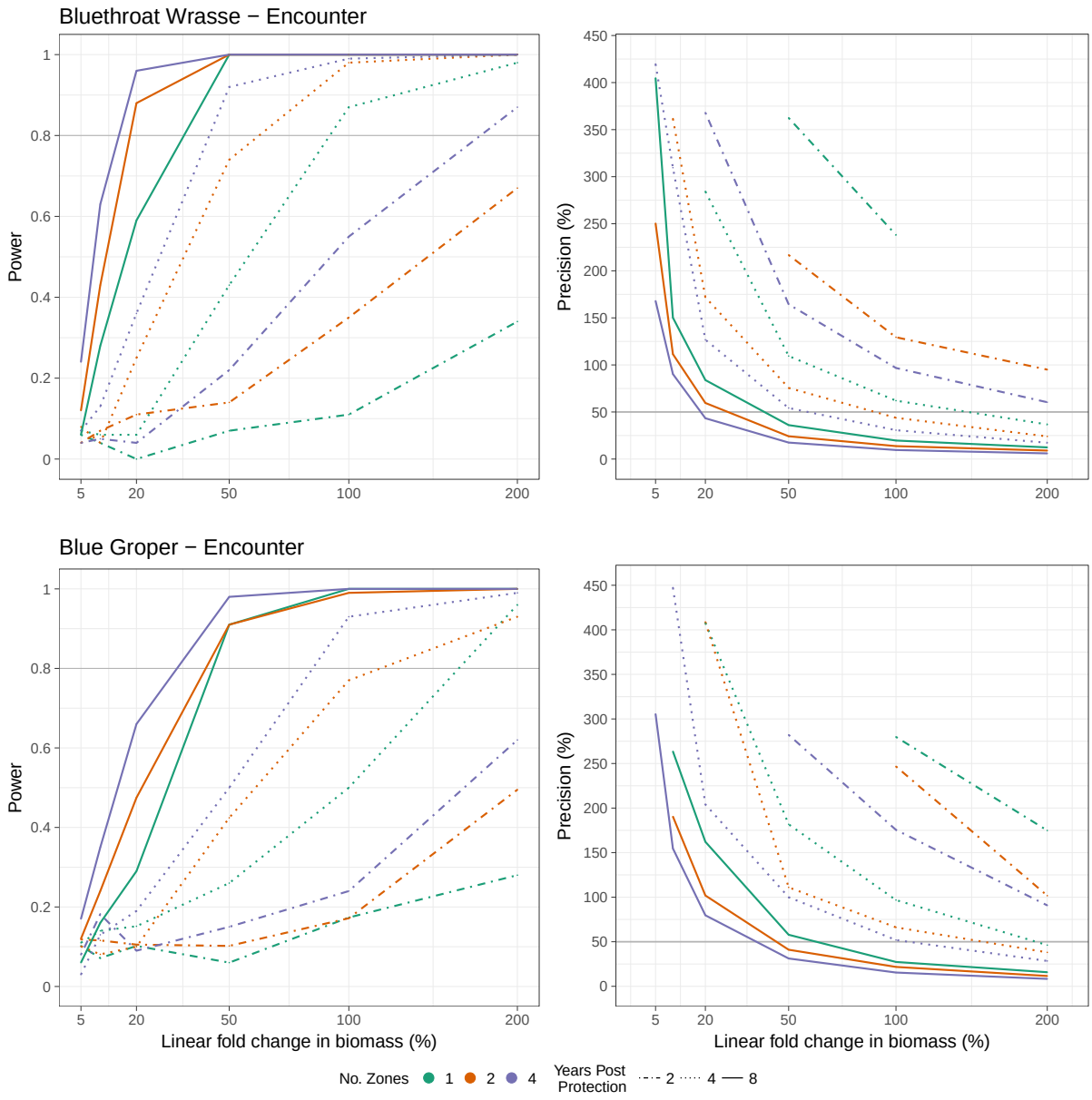

Figure 28. Power and precision of estimates of linear trends in biomass of Bluethroat Wrasse (upper row) and Blue Groper (lower row) for simulated fold changes from 5% (1.05 fold change) up to 200% (3 fold change). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

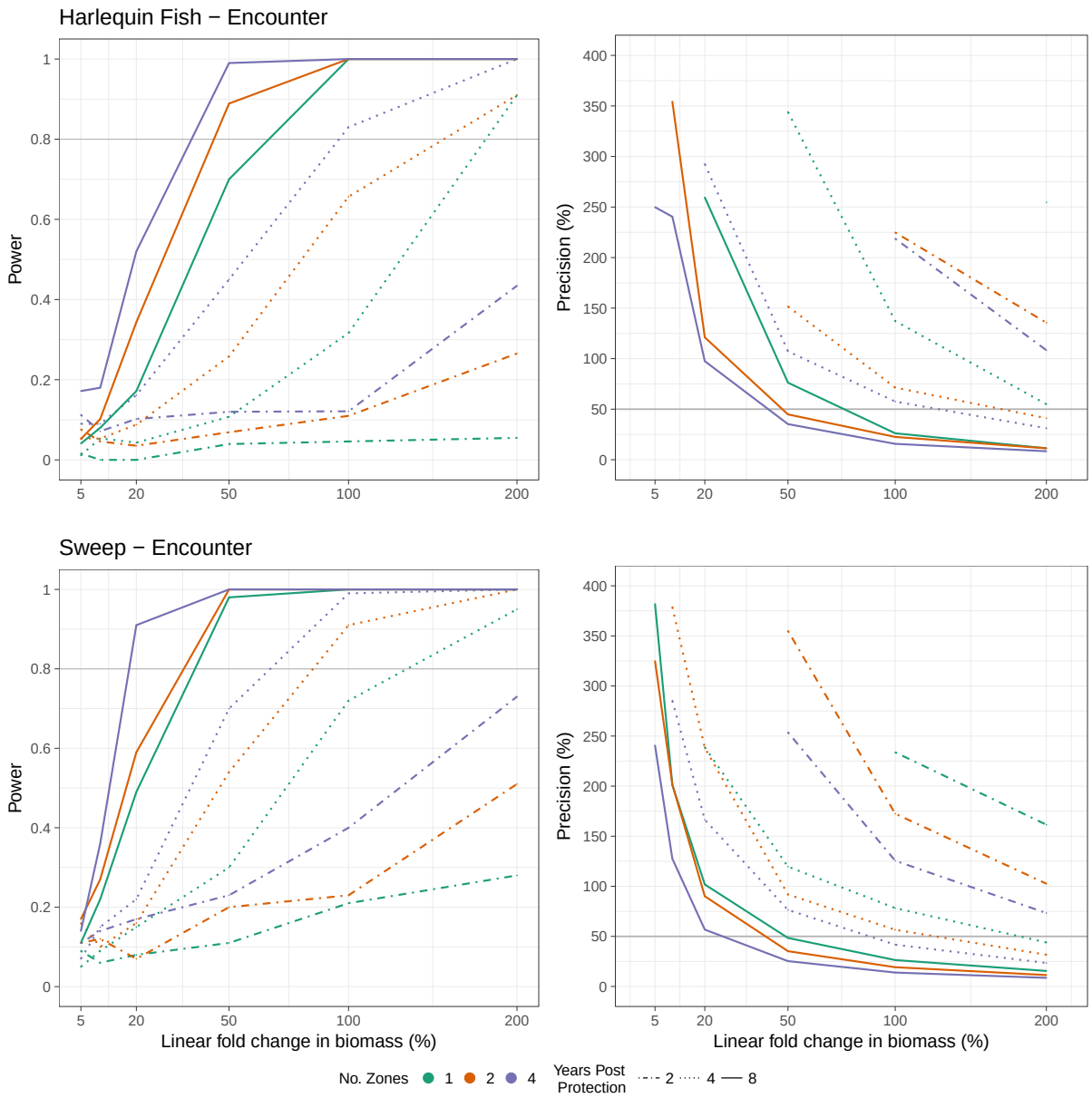

Figure 29. Power and precision of estimates of linear trends in biomass of Harlequin Fish (upper row) and Sweep (lower row) for simulated fold changes from 5% (1.05 fold change) up to 200% (3 fold change). Colours shows number of zones sampled; line types indicate number of years of monitoring after Marine Park establishment; grey dashed lines indicate power of 0.8 (left column) or precision of ± 50% (right column).

7.4 List of "fished" species

SPECIES	PHYLUM	CLASS	ORDER	FAMILY	AUTHORITY
Achoerodus gouldii	Chordata	Actinopterygii	Perciformes	Labridae	Richardson, 1843
Arripis georgianus	Chordata	Actinopterygii	Perciformes	Arripidae	Valenciennes, 1831
Arripis spp.	Chordata	Actinopterygii	Perciformes	Arripidae	
Arripis truttaceus	Chordata	Actinopterygii	Perciformes	Arripidae	Cuvier, 1829
Centroberyx gerrardi	Chordata	Actinopterygii	Beryciformes	Berycidae	Günther, 1887
Centroberyx lineatus	Chordata	Actinopterygii	Beryciformes	Berycidae	Cuvier, 1829
Cheilodactylus nigripes	Chordata	Actinopterygii	Perciformes	Cheilodactylidae	Richardson, 1850
Cnidoglanis macrocephalus	Chordata	Actinopterygii	Siluriformes	Plotosidae	Valenciennes, 1840
Dactylophora nigricans	Chordata	Actinopterygii	Perciformes	Cheilodactylidae	Richardson, 1850
Dasyatis brevicaudata	Chordata	Chondrichthyes	Myliobatiformes	Dasyatidae	Hutton, 1875
Equichlamys bifrons	Mollusca	Bivalvia	Ostreoida	Pectinidae	Lamark, 1819
Eubalichthys cyanoura					
Favonigobius lateralis	Chordata	Actinopterygii	Perciformes	Gobiidae	Macleay, 1881
Genypterus tigerinus	Chordata	Actinopterygii	Ophidiiformes	Ophidiidae	Klunzinger, 1872
Girella tricuspidata	Chordata	Actinopterygii	Perciformes	Kyphosidae	Quoy & Gaimard, 1824
Girella zebra	Chordata	Actinopterygii	Perciformes	Kyphosidae	Richardson, 1846
Haletta semifasciata	Chordata	Actinopterygii	Perciformes	Odacidae	Valenciennes, 1840
Haliotis laevigata	Mollusca	Gastropoda	Vetigastropoda	Haliotidae	Donovan, 1808
Haliotis roei	Mollusca	Gastropoda	Vetigastropoda	Haliotidae	Gray, 1827
Haliotis rubra	Mollusca	Gastropoda	Vetigastropoda	Haliotidae	Leach, 1814
Haliotis rubra complex	Mollusca	Gastropoda	Vetigastropoda	Haliotidae	
Haliotis spp.	Mollusca	Gastropoda	Vetigastropoda	Haliotidae	
Helicolenus percoides	Chordata	Actinopterygii	Scorpaeniformes	Scorpaenidae	Richardson, 1842
Heliocidaris erythrogramma	Echinodermata	Echinoidea	Echinoida	Echinometridae	Valenciennes, 1846
Heterodontus portusjacksoni	Chordata	Chondrichthyes	Heterodontiformes	Heterodontidae	Meyer, 1793
Jasus edwardsii	Arthropoda	Malacostraca	Decapoda	Palinuridae	Hutton, 1875
Kyphosus sydneyanus	Chordata	Actinopterygii	Perciformes	Kyphosidae	Günther, 1886
Leptomithrax gaimardii	Arthropoda	Malacostraca	Decapoda	Majidae	H. Milne Edwards, 1834
Meuschenia hippocrepis	Chordata	Actinopterygii	Tetraodontiformes	Monacanthidae	Quoy & Gaimard, 1824
Monacanthid spp.					
Mustelus antarcticus	Chordata	Actinopterygii	Tetraodontiformes	Triakidae	Günther 1870
Myliobatis australis	Chordata	Chondrichthyes	Myliobatiformes	Myliobatidae	Macleay, 1881
Nectocarcinus integrifrons	Arthropoda	Malacostraca	Decapoda	Portunidae	Latreille, 1825
Nectocarcinus spp.	Arthropoda	Malacostraca	Decapoda	Portunidae	
Nectocarcinus tuberculosus	Arthropoda	Malacostraca	Decapoda	Portunidae	A. Milne Edwards, 1860
Nemadactylus valenciennesi	Chordata	Actinopterygii	Perciformes	Cheilodactylidae	Whitely, 1937
Notolabrus parilus	Chordata	Actinopterygii	Perciformes	Labridae	Richardson, 1850
Notolabrus tetricus	Chordata	Actinopterygii	Perciformes	Labridae	Richardson, 1840
Octopus maorum	Mollusca	Cephalopoda	Octopoda	Octopodidae	Hutton, 1880
Octopus spp.	Mollusca	Cephalopoda	Octopoda	Octopodidae	
Othos dentex	Chordata	Actinopterygii	Perciformes	Serranidae	Cuvier, 1828
Pagrus auratus	Chordata	Actinopterygii	Perciformes	Sparidae	Bloch & Schneider, 1801
Paraplesiops meleagris	Chordata	Actinopterygii	Perciformes	Plesiopidae	Peters, 1869
Pelates octolineatus	Chordata	Actinopterygii	Perciformes	Terapontidae	Jenyns, 1840
Pempheris multiradiata	Chordata	Actinopterygii	Perciformes	Pempheridae	Klunzinger, 1879
Pentaceropsis recurvirostris	Chordata	Actinopterygii	Perciformes	Pentacerotidae	Richardson, 1845
Pinna bicolor	Mollusca	Bivalvia	Pterioida	Pinnidae	Gmelin, 1791
Platycephalid spp.	Chordata	Actinopterygii	Scorpaeniformes	Platycephalidae	
Platycephalus speculator	Chordata	Actinopterygii	Scorpaeniformes	Platycephalidae	Klunzinger, 1872
Portunus pelagicus	Arthropoda	Malacostraca	Decapoda	Portunidae	Linnaeus, 1758
Pseudocaranx georgianus	Chordata	Actinopterygii	Perciformes	Carangidae	Cuvier, 1833
Pseudocaranx spp.					
Pseudocaranx wrighti	Chordata	Actinopterygii	Perciformes	Carangidae	Whitley, 1931
Sardinops neopilchardus					
Scobinichthys granulatus	Chordata	Actinopterygii	Tetraodontiformes	Monacanthidae	Ramsay & Olgilby, 1886
Scorpis aequipinnis	Chordata	Actinopterygii	Perciformes	Kyphosidae	Richardson, 1848
Scorpis georgiana	Chordata	Actinopterygii	Perciformes	Kyphosidae	Valenciennes, 1832
Sepia apama	Mollusca	Cephalopoda	Sepioidea	Sepiidae	Gray, 1849
Sepioteuthis australis	Mollusca	Cephalopoda	Teuthoidea	Loliginidae	Quoy & Gaimard, 1833
Sepioteuthis spp.	Mollusca	Cephalopoda	Teuthoidea	Loliginidae	
Seriola hippos	Chordata	Actinopterygii	Perciformes	Carangidae	Günther, 1876
Seriola lalandi	Chordata	Actinopterygii	Perciformes	Carangidae	Valenciennes, 1833
Sillaginodes punctatus	Chordata	Actinopterygii	Perciformes	Sillaginidae	Cuvier, 1828
Sillago bassensis	Chordata	Actinopterygii	Perciformes	Sillaginidae	Cuvier, 1829
Sillago schomburgkii	Chordata	Actinopterygii	Perciformes	Sillaginidae	Peters, 1864
Siphamia cephalotes	Chordata	Actinopterygii	Perciformes	Apogonidae	Castlenau, 1875
Sphyraena novaehollandiae	Chordata	Actinopterygii	Perciformes	Sphyraenidae	Günther, 1860
Thamnaconus degeni	Chordata	Actinopterygii	Tetraodontiformes	Monacanthidae	Regan, 1903
Thysanophrys cirronasus	Chordata	Actinopterygii	Scorpaeniformes	Platycephalidae	Richardson, 1848
Upeneichthys vlamingii	Chordata	Actinopterygii	Perciformes	Mullidae	Cuvier, 1829
Urolophus cruciatus	Chordata	Chondrichthyes	Myliobatiformes	Urolophidae	Lacépède, 1804
Urolophus orarius	Chordata	Chondrichthyes	Myliobatiformes	Urolophidae	Last & Gomon 1987
Urolophus spp.	Chordata	Chondrichthyes	Myliobatiformes	Urolophidae	Müller & Henle, 1837

Table 5. List of 'fished' species (defined as "species that are susceptible to capture by conventional fishing methods - e.g., line, spear, pot, and net").

List of Tables

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